CALIFORNIA CLEAN FUELS MARKET ASSESSMENT 2003

CONSULTANT REPORT

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1. Executive Summary

1.1 Overview and Progress Since the Clean Fuels Market Assessment 2001

The California Clean Fuels Market Assessment is an essential element of the California Energy Commission's Alternative Fuels Infrastructure Program. It provides a foundation of logic to the infrastructure program by assessing California's most immediate infrastructure development needs for alternative transportation fuels and providing essential program recommendations on how to meet those needs. It is designed to provide a dynamic process for periodic reviews and updates that can be used by the California Energy Commission (Energy Commission) to set infrastructure goals and development priorities, assist in the preparation of legislative or administrative remedies, and help guide budget appropriations. The program targets expansion of fueling infrastructure for alternative-fuel vehicles and applications that will displace the greatest volumes of petroleum based fuels. Whenever possible, achieving quantifiable air-quality benefits is also an important objective.

Most importantly, the objectives of the Energy Commission's Alternative Fuels Infrastructure Program are consistent with, and complementary to, a variety of other State and federal activities that target reduced petroleum dependency and emissions in the transportation sector. Examples are listed below; specific ways in which the infrastructure program complements these efforts and can help meet specific goals are further described in this report.

Assembly Bill 2076 (Shelley, Chapter 936, Statutes of 2000) requires, as a significant component, the Energy Commission and the California Air Resources Board to develop and submit a plan to the Legislature to reduce petroleum dependence in California. Use of alternative fuels in the transportation sector is part of that plan.

Senate Bill 1170 (Sher, Chapter 912, Statutes of 2001) requires, as a major component, the Energy Commission, CARB and the Department of General Services to examine strategies to reduce petroleum consumption in the state fleet by no less than 10% on or before January 1, 2005.

Assembly Bill 1493 (Pavley, Chapter 200, Statues of 2002) requires CARB to develop and adopt regulations that reduce greenhouse gases emitted by passenger vehicles and light duty trucks.

Senate Bill 1389 (Bowen, Chapter 568, Statues of 2000) requires the Energy Commission to identify emerging energy trends and potential adverse social, economic or environmental impacts.

The inaugural version of the Market Assessment was completed in September 2001. Its focus was to recommend specific funding allocations for approximately $6 million in funds available from the Governor's 2000-01 Budget to the Energy Commission for the California Alternative Fuels Infrastructure Program. Candidate fuels assessed in the 2001 report for potential infrastructure funding included compressed natural gas (CNG), liquefied natural gas (LNG) and liquefied/compressed natural gas (LCNG), propane, fuel ethanol, fuel methanol, electricity for EV charging, and hydrogen (compressed or liquefied). In addition to such mainstream alternative fuels, a variety of "unconventional" liquid fuels (e.g., biodiesel, Fischer-Tropsch diesel) can potentially help California meet its petroleum reduction and clean air objectives. Because these may be blended into petroleum diesel without requiring special infrastructure, they are not the main subjects of this report.

Two basic types of recommendations were provided in the 2001 Market Assessment for potential infrastructure projects and activities: 1) allocate funds and resources prioritized by fuel and application type, or 2) defer potential funding, but monitor progress and consider further assessments.

Over the last two years the Energy Commission has allocated all $6 million of the existing funds to support alternative fuel infrastructure projects. Table 1 provides a summary of the three types of clean fuel fueling infrastructure projects that were funded by the Energy Commission as highest priority allocations. It shows that about $5.1 million of the available $6 million was expended to support a total of 41 projects, consisting of 19 CNG stations, 9 LNG stations (some of which included the "L/CNG" feature), and 13 propane stations. The total cost of these stations was about $29 million, of which the Energy Commission contributed 17.5 percent. The remainder of the $6 million was allocated to miscellaneous infrastructure-related projects and technology support activities, including $300,000 to cost share deployment of a hydrogen fueling station in conjunction with the California Fuel Cell Partnership.

Table 1.
Alternative Fuel Infrastructure Expenditures for Natural Gas and Propane

Station Type by Fuel	No. of Fueling Stations	Total Station Costs	Energy Commission Contribution	% of Commission Contribution
CNG	19	$13,582,184	$ 2,599,927	19.1%
LNG /LCNG	9	$14,218,932	$ 2,091,000	14.7%
Propane (LPG)	13	$ 1,197,877	$ 373,063	31.1%
	41	**$28,998,993**	**$ 5,063,990**	**17.5%**

1.2 Clean Fuels Market Assessment 2003 (Biennial Update)

This Clean Fuels Market Assessment 2003 provides a biennial update of the original 2001 document. A separate report entitled California Alternative Fuels Infrastructure Program Evaluation provides an analysis of the recent effectiveness of the Energy Commission's infrastructure development program in helping to broaden markets for clean fuels and displace petroleum fuels. Note: the specific focus of that report is the infrastructure expenditures listed in Table 1 above.

This Market Assessment 2003 describes the evolving landscape for regulatory and market drivers involving alternative fuel vehicles (AFVs) and their corresponding fuels. It updates what has happened in California's volatile energy and fuel markets since the near-crisis situation experienced during the 2000-2001 time frame, and the potential implications for AFV deployment. Details are provided about the types of vehicles and applications that hold the most potential to achieve displacement of petroleum fuels through deployment of AFVs. As described, high-fuel-use heavy-duty vehicle applications continue to offer an excellent focal point for clean fuel infrastructure development activities, but there are also certain light- and medium-duty applications (e.g., taxicabs and shuttle buses with high fuel use) that make good candidates for expanded use of alternative fuels.

Under the Energy Commission program, existing funds for clean fuel infrastructure development have been expended, but additional funds may be budgeted in the future. This report makes recommendations about potential new projects and activities that warrant the highest priority for ongoing support under the Energy Commission's program, in the form of immediate support activities or future funding allocations. The recommendations in this report are based on the assumption that further investments to diversify fuels in the transportation sector will help alleviate (rather than exacerbate) California's ongoing instability in transportation energy markets. Using the best-available information, these recommendations continue to focused on the most promising infrastructure deployments that meet the following criteria:

1. Offer strong potential to help meet the petroleum displacement targets of Senate Bill 1170 and Assembly Bill 2076,
2. Include key market and regulatory drivers to help ensure success,
3. Involve a full complement of stakeholders and participants needed for advancement of commercialization (e.g., engine and vehicle manufacturers, fuel providers, etc.),
4. Help deploy and support certified low- or zero-emission technologies,
5. Help expand the fueling network for end users in vehicle niches and applications that are strategic to long-term petroleum displacement efforts,
6. Provide collateral benefits such as expanding networks of public-access stations, and facilitating station sharing among neighboring fleets
7. Appear to entail the lowest risk to become "stranded" investments.

Specific findings and recommendations by vehicle type, application and topic are as follows:

1.2.1 Natural Gas Vehicles and Infrastructure

Natural gas continues to be the leading alternative fuel in California, in terms of commercially available low-emission vehicles and numbers of fueling stations specifically for automotive applications. Vehicles fueled by both CNG and LNG continue to grow in number, in response to regulations and incentive programs. It's feasible that tens of thousands of new natural gas heavy-duty vehicles (HDVs) will be deployed by 2007 in the western United States; many more will be on the road if industry objectives can be met. CNG continues to serve as a major alternative fuel for transit bus applications, as well as for various types of light- and medium-duty niche applications, such as taxicabs and shuttle vans. In addition to some major inroads into the transit bus niche, LNG has become a significant alternative to diesel in the refuse hauler, grocery chain, and return-to-base trucking applications.

Much progress with natural gas infrastructure development has been made since 2001. Over the last two years, the Energy Commission has cost-shared 28 new CNG, LNG and L/CNG stations using funds from the Alternative Fuels Infrastructure Development Program (refer back to Table 1). A separate report, the California Alternative Fuels Infrastructure Program Evaluation, provides greater details and assesses the prospects for these natural gas infrastructure expenditures to support the displacement of petroleum fuels over the next decade.

Although program funds are currently fully expended, extensive support for California's CNG and LNG infrastructure deployments are still both needed and justified. Corresponding vehicle and infrastructure investments could cost hundreds of millions of dollars over the next decade. This is approximately an order of magnitude higher than the amount invested over the last ten years. Large investments in both CNG and LNG fueling infrastructures will be needed if greater numbers of natural gas vehicles are to be deployed.

In addition, California should continue to be proactive in developing new means of production to obtain cost-competitive alternative transportation fuels. New actions are needed to reduce the state's ~85 percent dependency on imported natural gas, currently transported in by pipeline deliveries or LNG shipments that appear fully subscribed. Potential strategies to augment California's supply of clean transportation fuels include further exploiting its large untapped resources of waste-to-energy technologies, and using emerging gas-to-liquids technology to extract stranded reserves of associated natural gas, which can yield LNG, zero-sulfur synthetic diesel fuel, and methanol (among other useful products). These activities are needed in addition to existing efforts to develop small-scale liquefaction plants to produce LNG, using pipeline gas or remote gas sources.

To help meet all these needs, the following priorities are recommended for future funding allocations involving the natural gas fueling infrastructure:

Table 2.
Recommendations for Natural Gas Fueling Infrastructure Support

Recommended Type of Infrastructure Development / Support	State Effort Supported
Provide focused support of high-throughput LNG or CNG stations for use by refuse hauler fleets, return-to-base delivery fleets, and transit districts	AB 2076
Provide focused support of high- to medium-throughput CNG stations for school districts, high-fuel-use medium-duty fleets such as taxicabs, and small fleets using vehicle refueling appliances	AB 2076 SB 1170
Focused support of new L/CNG stations, or retrofit of existing LNG stations with the L/CNG feature, at locations offering an integrated NGV fueling strategy, i.e., fueling of light-, medium-, and heavy-duty vehicles at the same station	AB 2076 SB 1170
Support for commercialization and deployment of home refueling appliances,	AB 2076

in conjunction with efforts by DOE and other government agencies	SB 1170
Support for new gas-to-liquid technologies that can produce LNG cost-effectively or other useful transportation fuels (e.g., Fischer-Tropsch Diesel, which would entail relatively minor infrastructure investments).	AB 2076

1.2.2 Propane Vehicles and Fueling Infrastructure

Propane vehicles continue to have the potential to significantly displace petroleum fuels and in some cases provide air quality benefits in California. Over the last two years, the Energy Commission has cost shared 13 new propane stations using funds from the Alternative Fuels Infrastructure Development Program. As these stations come on line over the next few months, they will be used by Caltrans and other state fleets to fuel more than 1,000 bi-fuel pickup trucks. Historically, these vehicles have been driven exclusively on gasoline. Greater details and an assessment of the prospects for these propane infrastructure expenditures to displace petroleum fuels can be found in the California Alternative Fuels Infrastructure Program Evaluation.

Although program funds are currently expended, continued support for propane infrastructure under the California Alternative Fuels Infrastructure Program is both needed and justified. **Such support will help achieve California's petroleum-displacement objectives for both the shorter-term (SB 1170) and the longer-term (AB 2076).** Recent price volatility and supply issues for propane remain a concern, although this is the case with virtually all transportation fuels. It is difficult to estimate the exact potential of propane-fueled vehicles to displace gasoline and diesel due to the current limited offerings of dedicated propane vehicles, and the lack of any significant fuel-use requirements affecting bi-fuel vehicles. Ongoing monitoring is needed regarding commercialization of new propane-fueled vehicle and engine platforms. Strategic infrastructure support should continue, focused on fleets that have bi-fuel vehicles needing access to propane fueling, or those considering purchase of dedicated propane vehicles such as heavy-duty off-road yard hostlers or shuttle buses.

1.2.3 Electric Vehicles (EVs) and Recharging Infrastructure

With the latest modifications made by California Air Resources Board (CARB) to the zero emission vehicle (ZEV) requirement, it's doubtful that major automakers will make new full-function battery EVs commercially available before the 2005 model year. Based on actions and statements to date, automakers appear more likely to focus on producing advanced-technology, extremely low-emitting combustion vehicles that use gasoline. This includes hybrid-electric vehicles (hybrids) fueled by gasoline and diesel, which utilize electric-drive components and advanced batteries, but require no special fueling infrastructure. The numbers of low-speed EVs (also called "neighborhood electric vehicles") have risen significantly over the past two years, but these vehicles recharge from standard 110 volt outlets, and thus require no special charging infrastructure.

Currently there are 490 Inductive Charging locations (126 small paddle, 364 large paddle) and 297 Conductive locations.[1] Essentially, the need to build more charging stations for on-road EVs in California is “on hold” along with battery EV elements of the ZEV program itself, pending resolution of litigation and other matters. New investments in on-road EV charging using public funds may be prudent only after the technological landscape becomes better defined, presumably over the next several years. However, it is important to emphasize that renewed efforts to deploy on-road battery EVs could quickly return in California under certain circumstances (e.g., advancements in low-cost, high specific energy battery technology, or new developments announced by CARB’s to-be-appointed expert panel). Each update of the Clean Fuels Market Assessment can revisit the issue of EV infrastructure and the proper role for government funding. For example, it’s possible that new developments with neighborhood electric vehicles or “plug-in” hybrid electric vehicles will warrant further assessment of infrastructure requirements.

Also, it is notable that more than 300,000 non-road electric vehicles and equipment are currently operating in California (e.g., electric forklifts, burden and personnel carriers, airport ground support equipment), with a load exceeding 800 megawatts. Potentially, these non-road EVs could displace greater volumes of petroleum fuels through efforts to improve load-management and charging efficiency.

1.2.4 Ethanol Vehicles and Fueling Infrastructure

Ethanol is now replacing MTBE as the new oxygenate in California gasoline. California refiners are well along in their phaseout of MTBE and transition to gasoline blended with ethanol. Earlier concerns about potential shortages of ethanol have been alleviated – it now appears that the extensive demand for ethanol as an oxygenate can be met by existing supplies (with expected growth) and distribution channels.

Flexible fuel vehicles with the capability to operate on ethanol (E85) or gasoline are widely available in California. As of April 2003 more than 172,000 E85 FFVs were registered in California, and the number could reach 220,000 by the end of 2003.[2] Currently, E85 fuel is not available, and those FFVs are operated exclusively on gasoline. Switching to the use of E85 instead of gasoline in just a portion of the state’s 172,000 E85 FFVs would move California significantly forward in meeting the longer-term petroleum displacement goals of AB 2076.

Recent developments point to renewed potential for E85 fueling stations to be introduced into the state. These include 1) the industry’s announcement that at least one station will be opened, 2) CARB’s willingness to work with the industry to develop suitable vapor recovery technology for E85 stations, and 3) the stated support from one major automaker for a modest E85 infrastructure in California. The E85 industry plans to use the first deployment as an R&D venue to demonstrate that E85 stations can meet California’s tough vapor recovery requirements. Assuming this can be achieved, a major opportunity exists to build more E85 stations and begin displacing significant volumes of petroleum fuel in California’s large fleet of E85 FFVs.

It is recommended that progress and development of the new E85 station(s) be carefully monitored to determine if vapor recovery requirements are met and a system can be certified by CARB. Based on the results that emerge at this station and any new developments within the ethanol industry, future Clean Fuel Market Assessment updates should revisit the appropriateness of allocating Energy Commission funds to ethanol infrastructure.

1.2.5 Methanol Vehicles and Fueling Infrastructure

Methanol is an excellent carrier of hydrogen for use in fuel cells, and can also work well in vehicles with internal combustion engines. Currently, no major vehicle manufacturers are selling on-road vehicles that use methanol fuel, but this situation may change over the next decade if auto manufacturers decide to sell methanol-fueled fuel cell vehicles. Members of the California Fuel Cell Partnership (Partnership) have explored possible scenarios for developing a methanol fuel distribution system for fuel cell vehicles, and assessing commercialization issues, although levels of activity have slowed since 2001. Methanol infrastructure should remain a candidate for potential support under the California Alternative Fuels Infrastructure Development Program. Possible funding allocations or other means of support should be revisited with each new market assessment. It is anticipated that the Energy Commission's continued role as a key member of the Partnership will provide ongoing input regarding the types of fuel cell vehicle projects and assessments most worthy of support.

1.2.6 Hydrogen Vehicles and Fueling Infrastructure

Hydrogen is expected to be the long-term fuel for fuel cell vehicles. Achieving widespread use of direct-hydrogen fuel cell vehicles will require vehicle, fuel-production and infrastructure investments of very large proportions. Activities under the Partnership, which includes the Energy Commission, are addressing some of these issues. The Partnership has announced plans to begin demonstrating up to 60 fuel cell vehicles in 2003, and some vehicles have already been delivered. Beyond demonstrations, among the first vehicles that are likely to be commercially deployed are transit buses powered by fuel cells (similar to those that are already carrying passengers in public demonstration programs in several North American cities). However, CARB's recent modification of the ZEV regulation appears to provide new impetus for automakers to commercialize light-duty fuel cell vehicles. Initially, requirements under this compliance strategy are fairly modest -- up to 250 fuel cell vehicles might be deployed by 2008 -- but as many as 50,000 fuel cell vehicles could be on the road by 2017.

As of mid 2003, there are only a few facilities in California specifically designed to dispense hydrogen as a motor vehicle fuel. Examples include the two different systems used by Sunline Transit to fuel its direct-hydrogen fuel cell bus in the Coachella Valley, American Honda's station in Torrance, AC Transit's hydrogen station in Richmond, and the California Fuel Cell Partnership's station at its headquarters in West Sacramento. Over the last few years, the number of funding programs for hydrogen-fueling infrastructure has continued to grow. A notable recent development was President Bush's pledge in January 2003 that the federal government will provide $1.2 billion towards hydrogen infrastructure needed for deployment of fuel cell vehicles. In California, the Energy Commission has been a leader in supporting collaborative efforts to build new hydrogen fueling facilities for fuel cell vehicles. Much of this is being done in conjunction with the California Fuel Cell Partnership. Specific types of support from the Energy Commission include:

- Provision of $300,000 under the Budget Act of Fiscal Year 2000-2001 to the Santa Clara Valley Transit Authority to cost share design and construction of a hydrogen fueling facility.
- Provision of funding to support hydrogen fuel infrastructure demonstrations and critical studies (e.g., guidance for transit districts),
- Assistance with paths to fuel cell commercialization, from identifying potential problems associated with codes and standards, siting, safety, infrastructure, and fuel choice, to developing solutions to these problems,
- Increasing public awareness and enhancing opinion about fuel cell vehicles and hydrogen, to prepare the market for commercialization,
- Managing a study to assess and help overcome a variety of hydrogen fueling infrastructure issues (expected to be completed in the Spring of 2004), and
- Managing a grant funded by the U.S. Department of Energy to collect data and do field verification monitor activities at SunLine Transit Agency on a reformer that converts natural gas to hydrogen.

Hydrogen infrastructure should remain a primary candidate for future support under the California Alternative Fuels Infrastructure Program. It is anticipated that the Energy Commission's continued role as a key member of the California Fuel Cell Partnership will provide ongoing input regarding the types of projects and assessments most worthy of support.

1.2.7 Recommendations for AFV Infrastructure Incentives

An important ongoing need in advancing the commercial viability of clean fuel technologies is to implement effective, affordable and workable incentives. Many types of incentives have been used in California and other states to support AFV deployment, but some have clearly been more effective than others. Generally, state and local grants have provided the best motivation for fleets to purchase AFVs, whereas tax credits have worked well for individual AFV owners. In the past, some well-meaning but poorly designed and implemented incentive programs have resulted in ineffective use of funds or even a financial catastrophe (e.g., the Arizona program). Greater understanding is needed on the mechanics of effective incentives for AFVs and fueling stations. It is recommended that the Energy Commission and its partners conduct a detailed assessment of financial and administrative incentives that can most effectively help deploy AFVs to facilitate the maximum displacement of petroleum fuels. This assessment must take into account the complex and evolving landscape in California for regulations, the state budget, and other factors.

2. Introduction and Background

2.1 The California Alternative Fuel Infrastructure Program

Overall, about 50 percent of California's energy consumption results from transporting goods and people. With 34 million people and more than 24 million registered motor vehicles, California is the world's second largest consumer of gasoline and diesel fuel, exceeded only by the remainder of the United States. More than 99 percent of the state's transportation energy is derived from petroleum fuels. Statewide, there are approximately 9,500 retail fueling stations that dispense gasoline. About 14 billion gallons of gasoline are dispensed annually from those stations. On average, each station dispenses about 5,000 gallons of petroleum fuel each day. Including private fueling stations, nearly 16 billion gallons of gasoline and 5 billion gallons of diesel are consumed in California each year. Each year, gasoline demand is expected to grow between 1.6 and 3 percent.[3]

For several decades, the Energy Commission has worked with the CARB and other California public agencies to diversify the transportation fuels market by helping to develop a market for alternative AFVs. An essential element of these efforts has been parallel development of the necessary fueling infrastructures to support such vehicles.

The California Alternative Fuel Infrastructure Program was developed by the Energy Commission to facilitate the integrated development of fueling infrastructure for alternative fuels in California. This program allows the Energy Commission to track and promote competitive, non-petroleum energy alternatives throughout California, and oversee infrastructure development through project funding and incentives. In targeting expansion of the clean fuel infrastructure, the program addresses numerous alternative fuels and vehicle technologies, and allocates funds to support infrastructure development. Table 3 provides an overview of the program. Table 4 provides examples of alternative fuel stations that are candidates for further development under the program, along with the corresponding vehicle types and technologies, and the anticipated timeframe for development activities.

Table 3.
Overview of the California Alternative Fuel Infrastructure Program

Duration	♦ Multi-year, beginning Fiscal Year 2000-2001
Current Funding	♦ To be determined (historically, about 20% of total project costs) ♦ Approximately 4:1 cost sharing from other sources
Major Objectives	♦ Assess existing Alternative Fuel infrastructure ♦ Assess current and potential markets and technologies to set development goals ♦ Create economic market model for vehicle, market projection ♦ Coordinate infrastructure development ♦ Determine effective financial and administrative incentives to achieve goals ♦ Establish evaluative framework to measure and determine the success in attaining annual market development goals ♦ Provide an annual review and planning mechanism to guide future state investment and encourage private investment
Focus and Key Deliverables	♦ Clean Fuels Market Assessment, updated annually or bi-annually ♦ Master plan to guide public and private investments in non-petroleum fueling infrastructure ♦ Broad-based and targeted clean fuel infrastructure solicitations ♦ Continuously updated mechanism to determine and implement infrastructure development priorities ♦ Continued updates and renewed guidelines for investment of state funds in California's clean fuel infrastructure
Sources of Cost Sharing for Infrastructure Development	♦ Federal agencies (e.g., DOE) ♦ Other State agencies (e.g., CARB) ♦ Local agencies (AQMDs and APCDs) ♦ Private industry
Plan Participants, Stakeholders, and Sources of Input	♦ Technical Advisory Group (see Table 5) ♦ Alternative Fuel Industry members ♦ Energy Commission staff ♦ Consultants ♦ Academic community ♦ General public ♦ Associations

Table 4.
Examples of candidate clean fuels and vehicle technologies

Type of Clean Fuel Station	**Existing or *Potential* Users (Vehicles / Technologies)**
Compressed Natural Gas (CNG)	♦ **Internal Combustion Engine Vehicles** ♦ *Hybrid Electric Vehicles*
Liquefied Natural Gas (LNG)	♦ **Internal Combustion Engine Vehicles** ♦ *Hybrid Electric Vehicles*
L/CNG (capable of supplying both LNG and CNG)	♦ **Internal Combustion Engine Vehicles** ♦ *Hybrid Electric Vehicles*
Liquefied Petroleum Gas (Propane)	♦ **Internal Combustion Engine Vehicles** ♦ **Hybrid Electric Vehicles (Buses)**
Electric Charging	♦ **Battery Electric Vehicles** ♦ *"Plug-In" Hybrid Electric Vehicles*
Ethanol	♦ **Flexible Fuel Vehicles** ♦ *Hybrid Electric Vehicles* ♦ *Fuel Cell Vehicles (Reformer)*
Methanol	♦ *Internal Combustion Engine Vehicles* ♦ *Hybrid Electric Vehicles* ♦ *Fuel Cell Vehicles (Reformer)* ♦ *Fuel Cell Vehicles (Direct Methanol)*
Hydrogen	♦ **Internal Combustion Engine Vehicles** ♦ **Fuel Cell Vehicles (Direct Hydrogen)** ♦ *Hybrid Fuel Cell Vehicle (ICE / Fuel Cell)*

In addition to these mainstream alternative fuels, a variety of "unconventional" liquid fuels can potentially help displace petroleum fuels in California. These include biodiesel, Fischer-Tropsch diesel, and Pure Energy's P-Series fuel. Such fuels hold promise to displace petroleum fuels and further diversify the fuel mix in California's transportation sector – for example, the City of Berkeley announced in June 2003 that it will convert nearly 200 vehicles to 100% biodiesel ("B100").[4] In some cases, these fuels and technologies also provide significant air quality benefits. The immediate infrastructure needs in California for these fuels tend to be minimal or require further definition,[5] but such fuels should remain candidates for future allocations under the Energy Commission's Plan. Barriers and problems associated with using such fuels on a wider scale may also exist. Thus, assistance for these fuels beyond infrastructure development (e.g., further studies, policy support) may be warranted, given the substantial potential benefits at minimal budget impact to the State.

For the purposes of guiding the most immediate activities under the Energy Commission's infrastructure development program, this assessment focuses on the following "conventional" alternative transportation fuels: natural gas, propane, ethanol, methanol, electricity and hydrogen. These fuels face the most challenging fueling infrastructure barriers, which currently impede wider commercial deployment of AFVs and the associated displacement of petroleum fuels.

2.2 Relationship of Infrastructure Development Program to Other State Efforts

The objectives of the Energy Commission's Alternative Fuels Infrastructure Program are consistent with, and complementary to, a variety of other State and federal activities that target reduced petroleum dependency in the transportation sector. Examples are briefly described below; specific ways in which the infrastructure program complements these efforts are further described in this report.

Assembly Bill 2076 (Shelley, Chapter 936, Statutes of 2000) requires the Energy Commission and the California Air Resources Board to develop and submit a plan to the Legislature to reduce petroleum dependence in California. This plan provides a policy framework to reduce petroleum consumption in the state fleet over the next several decades, and will be the foundation of the state's transportation energy policy. In July 2003, recommendations of the final draft AB 2076 report were released. One recommendation is that California should "establish a goal to increase the use of non-petroleum fuels to 20 percent of on-road fuel consumption by 2020 and 30 percent by 2030."

Senate Bill 1170 (Sher, Chapter 912, Statutes 2001) requires the Energy Commission, CARB and the Department of General Services to examine strategies to reduce petroleum consumption in the state fleet by no less than 10% on or before January 1, 2005. A resulting report to the Legislature found that exclusively using alternative fuels (CNG or propane) in the state's fleet of 3,572 bi-fuel vehicles would achieve nearly 75% of the targeted reductions in petroleum use.[6] The report noted that achieving this goal would require major expansion of the existing fueling infrastructure available to state fleets using bi-fuel vehicles.

The Driving Green Task Force is a collaboration of 25 state agencies (led by the State and Consumer Services Agency) that is addressing many of the topics and barriers under SB 1170. This task force may serve as a policy and planning mechanism to implement many of the SB 1170 report recommendations, including those involving alternative fuels.

Assembly Bill 1493 (Pavley) requires CARB to develop and adopt regulations that reduce greenhouse gases emitted by passenger vehicles and light duty trucks. Transportation is California's largest source of carbon dioxide, with passenger vehicles and light duty trucks creating more than 30 percent of total climate change emissions. Greater use of dedicated alternative fuel vehicles represents a potential way for auto manufacturers to comply with AB 1493.

The Joint Agency Climate Team (JACT) is a group of more than 15 state agencies chaired by CARB, which develops policy and program initiatives to reduce greenhouse gas emissions, including those related to AB 1493.

Senate Bill 1389 (Chapter 568, Statues of 2000; Bowen) requires the Energy Commission to identify emerging energy trends and potential adverse social, economic or environmental impacts. The Energy Commission's inaugural Integrated Energy Policy Report (IEPR) will address the requirements of SB 1389 and is due November 2003. This effort, to be updated biennially, includes a transportation energy report that will discuss trends, issues and recommendations for on-road gasoline and diesel use in California.

2.3 Technical Advisory Group

To assist the Energy Commission in developing and implementing the Plan, a Technical Advisory Group (TAG) was formed in mid 2000. Five primary types of stakeholders are represented on the TAG, with many different individual organizations contributing a wide range of expertise (see Table 5).

Table 5.
Stakeholder organizations represented on the Technical Advisory Group

Stakeholder Type	Name of Organization / Agency Represented on the TAG	Primary Area of Specific Expertise and / or Contribution
Private Sector Fleets and End Users	♦ SunLine Transit Agency ♦ Los Angeles County Metro Transit Authority ♦ Jack B. Kelley, Inc ♦ California Fleet	♦ Transit Buses ♦ Transit Buses ♦ HD Trucks ♦ End User
Utilities, Fuel Suppliers and Infrastructure Industry	♦ Methanex Corporation ♦ Pinnacle CNG Systems LLC ♦ Trillium USA ♦ Pacific Gas & Electric ♦ The Gas Company / Sempra Energy ♦ Clean Energy (formerly ENRG, Pickens Fuel) ♦ FleetStar / Applied LNG Technologies ♦ Parallel Products ♦ Delta Liquid Energy	♦ Methanol Supplier ♦ CNG Turnkey Provider ♦ CNG Turnkey Provider ♦ CNG Gas Utility ♦ CNG Gas Utility ♦ CNG / LNG Turnkey Provider ♦ CNG, LNG, L/CNG Supplier ♦ Ethanol / E85 ♦ LPG / Propane Supplier
Government Agencies	♦ California State Department of Education ♦ California Department of General Services ♦ San Joaquin Valley APCD ♦ California Air Resources Board ♦ SCAQMD ♦ California Department of Transportation ♦ California Department of Fish & Game ♦ California Department of Parks and Rec.	♦ AFV User ♦ AFV User ♦ Incentives, Technology ♦ Incentives, Regulations ♦ Incentives, Regulations ♦ AFV User, Traffic mitigation ♦ AFV User ♦ AFV User
Trade Associations, Consultants, Research Institutes and National Laboratories	♦ California Natural Gas Vehicle Coalition ♦ Gas Technology Institute ♦ California Electric Transportation Coalition ♦ Argonne National Laboratory ♦ DOE Clean Cities ♦ Gladstein & Associates ♦ DOE/NREL	♦ NGVs and Infrastructure ♦ NGVs and Infrastructure ♦ EVs and Infrastructure ♦ Various AFV Technologies ♦ Infrastructure Coalitions ♦ ICTC and LNG Consultant ♦ AFV Technologies
Vehicle and Engine Manufacturers	♦ Ford Motor Company ♦ American Honda Motor Company ♦ Toyota Motor Sales ♦ Cummins Engine CompanyWestport Inc. ♦ Daimler-Chrysler Corporation/Detroit Diesel ♦ General Motors	♦ AFVs and Infrastructure ♦ AFVs and Infrastructure ♦ AFVs and Infrastructure ♦ Heavy-Duty AFV Engines ♦ AFVs and Infrastructure ♦ AFVs and Infrastructure

2.4 Overview of the Clean Fuels Market Assessment

The Clean Fuels Market Assessment is a foundation and essential element of the California Fuel Infrastructure Development Plan. The objective of the Market Assessment is to assist the Plan in accomplishing the following:

- Identify and analyze barriers and impediments to expanding the alternative fuels infrastructure in California,
- Set realistic and practical development goals for alternative fuel infrastructure,
- Help develop effective financial and administrative incentives,

- Assist in the preparation of legislative or administrative remedies,
- Conduct public outreach to stimulate private participation and investment,
- Serve as an adjunct to the annual Program Workplan process,
- Assist in the selection of infrastructure-development activities for funding,
- Assist to develop priorities and plan activities,
- Conduct public outreach and education
- Identify fuel-specific issues (supply/price).

In September of 2001, the inaugural California Clean Fuels Market Assessment was prepared. This report identified specific development goals to improve the alternative fuels market within California. Using the recommendations within the 2001 Market Assessment as a guide, the Energy Commission co-funded 32 alternative fuel infrastructure grants for 41 AFV stations dispensing natural gas and propane during the period from mid 2001 to early 2003. (Refer back to Table 1 on Page 2). The Energy Commission also co-funded a hydrogen fueling station at Santa Clara Valley Transit. The total contribution made under the Energy Commission's infrastructure program for these projects was about $5.4 million.

A separate report entitled California Alternative Fuels Infrastructure Program Evaluation provides an analysis of the recent effectiveness of the Energy Commission's infrastructure grants in helping to broaden markets for clean fuels and displace petroleum fuels.

2.5 Scope, Information Sources and Limitations

Key California-specific components identified in this assessment include:

- Existing infrastructure and vehicle base, by fuel type,
- Discussion of technological maturity,
- Fuel-specific considerations (e.g., vehicle performance, range, cost, fuel supply, public access, card reader access),
- Building codes and standards,
- Existing and potential funding sources and mechanisms, and
- Existing and potential incentives (financial and administrative).

As with the original report, a variety of data and information sources were used in preparing this Clean Fuels Market Assessment 2003. Updates and revisions to the 2001 version were received from various TAG members from the organizations identified in Table 5. Additional input was provided by Energy Commission staff and various organized groups involved with alternative fuel infrastructure issues. These include the California Natural Gas Vehicle Coalition, the California Natural Gas Vehicle Partnership, the California Fuel Cell Partnership, and others.

Using information obtained from these various sources, this Market Assessment 2003 provides guidance towards continued support and expanded deployments of clean fuel stations in California to assist in displacement of petroleum fuels. The following caveats and limitations are noted:

- California has experienced significant perturbations in its energy markets over the last several years. Virtually all transportation fuel markets have been affected, and new developments continue to occur regularly. This report attempts to assess likely ways in which such energy market perturbations may impact potential AFV infrastructure projects. The recommendations provided in this report continue to assume that, over the longer run, further investments to diversify fuels in the transportation sector will help alleviate (rather than exacerbate) California's ongoing energy issues.

- In the process to update this report, not all TAG members responded to requests for input. For all information that was received, reasonable attempts were made to corroborate the input and clarify or expand where important. However, rigorous verification of the information provided is beyond the scope of this study.

- On-road applications for clean fuels are highlighted in this report; however, many off-road vehicles (e.g., construction, military, airport, marine) use the same alternative-fuel engines that are described in this report. Therefore, much of the findings and conclusions of this study can be extrapolated to off-road vehicle sectors.

2.6 Major Drivers for Use of Alternative Fuels

Three main categories of on-road vehicles consume the vast majority of gasoline and diesel fuel in California: light-duty vehicles (LDVs), medium-duty vehicles (MDVs) and heavy-duty vehicles (HDVs). Generally, LDVs and MDVs are powered by gasoline engines, and HDVs are powered by diesel engines. Today there are no significant energy-related regulations that drive the use of alternative fuels in these vehicle sectors. Regulations such as the Energy Policy Act (EPACT) and Corporate Average Fuel Economy (CAFÉ) standards have helped deploy vehicles *capable* of using alternative fuels, such as bi-fuel vehicles and flexible-fuel vehicles (FFVs). CAFÉ regulations have been particularly important as a driver for wide-scale deployment of FFVs by the major automakers (see Section 3.1.4). Manufacturers earn CAFÉ incentives for the sale of FFVs (and other types of AFVs) beyond what they receive for conventional gasoline vehicles. These incentives allow manufacturers to raise their CAFÉ values, regardless of what fuel is ultimately purchased by end users for the FFVs sold. In this way, light-duty vehicle manufacturers have been strongly motivated to offer the flexible-fuel feature as standard equipment on as many vehicle types as possible. Bi-fuel vehicles (propane or natural gas versions) are sold primarily because they are in demand by fleets subject to EPACT requirements, but fleets can comply while exclusively using gasoline. Thus, no requirements or incentives currently exist that have been effective in deterring fleets from the common practice of primarily using gasoline in their flexible-fuel or bi-fuel vehicles. Currently, neither EPACT nor CAFÉ applies to heavy-duty vehicles. California's air pollution control laws have been important regulatory drivers towards *dedicated* AFVs, which are more optimized for a specific alternative fuel. To some extent, the commercial viability of specific clean fuels and technologies continues to depend on their ability to provide emission reductions. In California, LDVs, MDVs and HDVs each contribute significantly to the overall emission inventory, and are being aggressively targeted for further emission reductions. However, there are significant differences among these categories in the magnitude of emission reductions that are likely to result from alternative fuels. Because the emissions competitiveness of conventionally fueled vehicles continues to improve, over the longer term it's unclear to what degree and how long air quality regulations can continue to be a major driver towards further AFV deployment.

The appendix on page 109 provides a detailed discussion on the emission competitiveness of AFVs versus diesel and gasoline vehicles. It focuses on the HDV sector, where currently the largest emission reductions can be realized using alternative fuels – although strong competition to meet new emission standards is on the horizon from advanced diesel technologies. By 2010, both diesel and alternative-fuel heavy-duty engines will need to emit about 90 percent less NO_x and PM than today's cleanest alternative fuel engines. This will be challenging for both advanced diesel and alternative fuel engines. As of mid 2003, certified diesel engines have significantly "farther to go" to reach the target levels, but a number of advanced control technologies show strong potential.

Beyond emission considerations, certain types of HDVs are conducive to using alternative fuel for the following reasons:

- Most of the operating costs of HDVs are attributable to purchasing fuel; this makes the economics of using clean fuels more attractive (historically, at least, natural gas has been cheaper than petroleum fuels).

- Most HDVs are centrally fueled at large yards by professionally trained fueling and maintenance personnel; this can help defray the higher costs associated with using and maintaining alternative fuel vehicles and fueling stations.

- Large HDV "anchor" fleets can provide the minimum fuel throughput levels needed to make alternative fuel stations economically attractive to entrepreneurs and venture capitalists.

For all the reasons discussed above, HDVs remain the most attractive vehicle sector to target for displacement of petroleum fuel and emissions reductions using alternative-fuel engines. Specific vehicle types that are well suited include transit buses, return-to-base delivery trucks, and refuse haulers. Expanded deployment of clean fuel technologies in these applications (as well as others) largely depends on continued progress with infrastructure development. High-fuel-use HDV applications offer the best focal point for such development activities. However, there are also certain LDV and MDV applications (e.g., taxicabs and shuttle buses with high fuel use) that also make good candidates for expanded use of alternative fuels. Detailed findings and recommendations are discussed further in subsequent sections of this report.

2.7 Avoidance of "Stranded" Investments, and Criteria for "Exit" Strategies

One legitimate concern when allocating public funds towards the deployment of alternative fuel infrastructure is the possibility of "stranded investments." For the purposes of the Energy Commission's alternative fuel infrastructure program, stranded investments might be considered allocations that ultimately do not significantly displace gasoline or diesel consumption. Examples of scenarios in which today's infrastructure investments could become stranded include the following:

- A particular alternative fuel becomes cost prohibitive, or its supply can't meet demand, leading to severe under-utilization of newly constructed fueling stations,

- Vehicle and/or engine manufacturers fail to sell, manufacture or market sufficient numbers of an AFV type, or they unexpectedly phase out existing products,

- End users refrain from purchasing today's AFVs in hopes of obtaining longer-term, more advanced technology at a later date,

- Miscellaneous unforeseen circumstances occur (e.g., health & safety problems with a fuel or technology), and

- Technological breakthroughs with conventionally fueled vehicles or competing AFV types render another AFV type unable to compete.

As one example, consider the AFV infrastructure investments currently being made in natural gas fueling facilities. Some parties have claimed that large investments of this type for transit buses (in response to CARB's transit bus rule or SCAQMD's Rule 1992) could become stranded when transit districts are required to begin procuring zero-emission buses in the 2008 to 2010 time frame. CARB considered this issue in adopting its transit rule, but concluded that the purchase of natural gas buses will have "strong viability" at least until model year 2015. CARB staff also noted that "the existing natural gas infrastructure will be transferable to the operation of fuel cell buses and could substantially reduce the infrastructure cost for fuel cell bus fleets."[7] This is because reforming of natural gas at transit districts will be one option to obtain hydrogen for fuel cell buses, and technologies used to compress natural gas and store it on buses may be partially transferable to hydrogen. Some transit agencies, such as SunLine Transit Agency[8] in Southern California's Coachella Valley, are taking an integrated approach for the long term, and are intentionally using their deployment of natural gas buses as a stepping-stone strategy towards hydrogen fuel cell buses.

A second concern when allocating public funds for AFV fueling stations is how to determine when such support is no longer needed. Complex issues are involved in defining success, and determining when it has been achieved. For example, several turnkey natural gas providers now consider high-throughput CNG and LNG stations to be commercially sustainable. This is the case largely due to government incentive funds that have encouraged HDV fleets to procure NGVs. Those same types of fleets may continue to need some government funding to offset higher operational costs. Fleets that don't consume large fuel volumes often need both vehicles and fueling stations subsidized. Building public-access stations is costly and currently only profitable for the highest-volume stations; consequently, government funds may be needed to provide this desirable feature. In summary, defining success and determining an exit strategy for government funding can be a complex and dynamic process.

These issues faced by government agencies funding AFV programs – how to avoid stranded investments and what criteria to use for exit strategies – require careful monitoring and dynamic response. The stakes are significant, given the magnitude of incentive funding available in California today for AFVs and fueling infrastructure. As described in this report, significant uncertainties periodically arise regarding price, supply and demand for conventional transportation fuels as well as competing alternatives. To determine which of these parameters could negatively impact AFV markets and lead to stranded infrastructure investments, it will be necessary to continually assess and periodically update the latest trends. Similarly, it will be necessary to perform ongoing assessments of progress towards sustainable commercialization, to determine the appropriate points to phase out government investments. It is for these reasons that the Clean Fuels Market Assessment is updated on a regular basis (e.g., bi-annually).

The funding available for allocations under the California Alternative Fuels Infrastructure Program continues to be relatively small compared to the magnitude of infrastructure investments needed, by both government agencies and the private sector. Therefore, the Energy Commission's program is focused on the most promising infrastructure deployments that 1) need government funds to become commercially self-sustaining, and 2) appear to entail reasonable risk that they won't lead to stranded investments.

3. Status of Clean Fuel Vehicle Technologies in California

3.1 Near-Term Fuel / Vehicle Technologies

Over the last decade, alternatively fueled LDVs, MDVs, and HDVs using a wide range of technologies and fuels have been deployed in California for a wide range of technologies and fuels. These include "flexible-fuel" vehicles using any combination of 85 percent methanol or ethanol blended with gasoline; "bi-fuel" light-duty vehicles that were designed to operate on a gaseous fuel or gasoline; and trucks and buses powered by "dedicated" methanol, propane or natural gas engines. In a variety of applications, many types of these alternative fuel vehicles (AFVs) have been successful in penetrating commercial vehicle markets. However, AFVs are still being deployed in insufficient numbers to achieve self-sustained commercialization. The major barriers to wide-scale commercialization of AFVs have included (1) higher capital costs of the vehicles and engines compared to conventional vehicles, and (2) higher costs of fueling stations that dispense alternative fuels, and the limited numbers of such stations. These barriers are closely related through a classic "chicken or the egg" problem, i.e., which will come first: adequate numbers of AFV fueling stations to stimulate wider production of affordable AFVs, or sufficient sales of AFVs to justify the building of new alternative fuel stations?

As a prelude to the key issue of this assessment – alternative fuel infrastructure development – the following sections provide an overview of various AFV types that are now commercially available in California, or have the potential to be introduced over the next five years.

3.1.1 Natural Gas Vehicles

Commercially Available Vehicles / Technological Maturity

A wide variety of natural gas vehicles (NGVs) are commercially available today from U.S. engine and vehicle manufacturers. Available products have emerged over recent years in virtually all on-road applications, including transit buses; school buses; refuse haulers; street sweepers; light-, medium- and heavy-duty trucks; cargo or passenger vans; and passenger cars. In terms of numbers deployed, the most common NGV types in America are on-road light- and medium-duty vehicles fueled by compressed natural gas (CNG). Many of these vehicles are so-called "dual-fuel" or "bi-fuel" vehicles, because they are capable of being operated on gasoline or CNG. However, as further described in this report, vehicles that operate exclusively on CNG ("dedicated" NGVs) are also available, and provide more compelling societal benefits. Table 6 provides examples of light- and medium-duty vehicles that are commercially available as dedicated or dual-fuel CNG vehicles.

Table 6.
Recent model light- and medium-duty CNG vehicles sold in California

Maker	CNG Vehicle	Engine Displacement	Type of Natural Gas Engine
Ford	♦ Econoline E-450 Cut Away ♦ Econoline Van / Wagon ♦ F-Series Light Duty Pickup	5.4 Liter V8	Dedicated CNG
Ford	♦ Crown Victoria Sedan	4.6 Liter V8	Dedicated CNG
Daimler-Chrysler	♦ Ram Van / Wagon 2500 ♦ Ram Van / Wagon 3500	5.2 Liter V8	Dedicated CNG
Acura	♦ MDX SUV	3.5 Liter V6	Dedicated CNG
Honda	♦ Civic GX	1.7 Liter L4	Dedicated CNG
Toyota	♦ Camry Sedan[a]	2.2 Liter L4	Dedicated CNG
Ford	♦ F-Series Light Duty Pickup	5.4 Liter V8	Bi-Fuel CNG / Gasoline
GM	♦ Express / Savana	5.7 Liter V8	Bi-Fuel CNG / Gasoline
GM	♦ Chevy Cavalier Sedan	2.2 Liter L4	Bi-Fuel CNG / Gasoline

[a]The Camry was discontinued after the 2000 model year.

Heavy-duty vehicles equipped with dedicated natural gas engines[9] are also commercially available for multiple applications from a variety of manufactures. Initially, commercial offerings were dominated by CNG-fueled versions specifically targeted for the transit bus market. In more recent years, LNG-fueled versions have also been offered, for both transit and heavy-duty trucking applications. The choices available today for these key HDV sectors are highlighted in Table 7, which lists the 2003 and 2002 model-year heavy-duty natural gas engines (CNG and LNG) that have been certified to CARB's Optional NO_x Emission Credit Standards. These are among the lowest-emitting heavy-duty engines ever certified for use in California. To date, no conventionally fueled engines have achieved these standards (see Section 6 for further discussion about the long-term emission competitiveness of AFVs versus conventional fuels).

Table 7.
Recent model H-D natural gas engines certified to CARB's Low-NO_x Emission Standards

MY	Manuf.	Service Type[a]	Fuel Type	Displ (ltr)	Cert. Std. NOx (g/bhp-hr)	Cert. Std. NOx+NMHC[c] (g/bhp-hr)	HP
2003	Cummins	MHD	LNG CNG	5.9	-	1.8	195/200/230
2003	Cummins	MHD	LNG CNG	8.3	-	1.8	250/275/280
2003	Cummins	BUS	LNG CNG	8.3	-	1.8	250/275/280
2003	DDC	UB	CNG LNG	8.5	-	1.2	275
2003	Deere	MHD	CNG	8.1	2.5	-	250
2002	Baytech	HDG	CNG	5.7	1.5	-	211
2002	Baytech	HDG	Dual[b]	5.7	1.5	-	211/245
2002	Cummins	MHD	CNG	8.3	2.0	-	250/275/280
2002	Cummins	BUS	CNG	8.3	2.0	-	250/275/280
2002	Cummins	MHD	CNG	5.9	2.5	-	150/195/230
2002	Cummins	MHD	LNG	5.9	2.5	-	195
2002	DDC	BUS	LNG CNG	8.5	2.0	-	275
2002	DDC	BUS	LNG CNG	12.7	2.5	-	330/400
2002	Deere	BUS	CNG	8.1	2.0	-	275/280
2002	Deere	MHD	CNG	8.1	2.5	-	250
2002	Ford	HDG	CNG	5.4	0.5	-	225
2002	GFI	HDG	CNG	6.8	1.5	-	245
2002	GFI	HDG	LPG	6.8	1.5	-	310
2002	PSA[d]	HHD	Dual [e]	7.2	2.5	-	200/250
2002	PSA[d]	HHD	Dual [e]	10.3	2.5	-	315/350
2002	PSA[d]	HHD	Dual [e]	12.0	2.5	-	370/410

[a]Service Type: MHD (Medium Heavy-Duty); HHD (Heavy Heavy-Duty); UB (Urban Bus); HDG (Need this!); [b] Dual fuel (CNG + gasoline); [c]NOx + non-methane hydrocarbons effective for engines manufactured on or after Oct. 1, 2002; [d]Power Systems Associates (using Caterpillar engines); [e]Dual Fuel (CNG + Diesel; or LNG + Diesel)

Source: California Air Resources Board website, updated February 10, 2003

Despite this variety of vehicle types and accommodating applications that can deliver compelling societal benefits,[10] the volume of conventional fuels displaced by CNG or LNG in California's transportation sector remains negligible. One reason is that regulatory drivers for alternative fuels have been marginally effective. For example, in the light- and medium-duty sector, the federal Energy Policy Act (EPACT) allows bi-fuel NGVs to be operated on gasoline while still qualifying as "alternatively fueled."[11] Affected fleets have therefore been slow to utilize the natural gas fuel option or incorporate dedicated NGVs, resulting in very low fuel use. Except in certain applications and geographic areas of California, heavy-duty fleets are not required to use alternative fuels and may not be motivated by environmental benefits.

This perpetuates one of the biggest barriers for natural gas vehicles: the fueling infrastructure remains both limited and under utilized. Today, there are approximately 180,000 gasoline stations in the U.S.[12] compared to only 1,200 natural gas vehicle fueling stations[13], of which about 250 are in California. Most of these are CNG stations, some of which have been especially expensive to build, operate and maintain relative to the volumes of fuel dispensed. Approximately 100 "public-access" CNG stations exist in California – these stations tend to dispense the lowest volumes of fuel, for reasons further described below.

To maximize the most favorable economics and address major regulatory drivers (see Appendix: Air Quality Regulations and Petroleum Displacement), the focus of NGV commercialization has largely shifted towards fleets with heavy-duty trucks, transit buses, and refuse haulers. As Table 8 shows, on average NGVs in these categories consume thousands of gasoline-gallon equivalents (GGEs) of natural gas each year – significantly more than most light- and medium-duty NGVs.[14] HDVs are usually centrally fueled and maintained -- also conducive to the economics and logistics of using alternative fuels.

Table 8.
Largest fuel users by vehicle type / application.

Vehicle Class	Annual Miles per Vehicle	Miles Per Gallon (gasoline or diesel equivalent)[15]	Gallons per Year per Vehicle
Transit Buses	40,000	3.5 dge	11,430
Refuse Trucks	20,000	2.0 dge	10,400
HD Trucks (Class 6-8)	65,000	6.5 dge	10,000
Shuttle Vans	90,000	12.0 gge	7,500
Taxis	90,000	15.0 gge	6,000
School Buses	15,000	5.0 dge	3,000
MD Trucks (Class 3-6)	25,000	11.0 gge	2,270
LD Trucks	15,000	15.0 gge	1,000
Automobiles	19,200	24.0 gge	800
Source: Gas Technology Institute, "NGVs – Year 2000 Report: Research, Development Demonstration and Deployment," 2000			

The specific heavy-duty vehicle sectors that use these natural gas engines are growing rapidly, as Table 9 shows, and there have been some significant success stories. For example, data collected by the American Public Transportation Association (December 2001) indicates that at least 6,300 natural gas transit buses are now in service at 86 transit districts nationwide; this represents about 11 percent of all existing U.S. transit buses. California is home to 21 of these transit agencies using natural gas (LNG or CNG). Topping the list of transit districts using the greatest numbers of natural gas buses is the Los Angeles Metropolitan Transit Authority (MTA), which has nearly 2,000 CNG buses currently in service or under near-term order. Orange County Transit District operates 232 LNG buses, and is in the process of making new procurements. Nationwide, about 22 percent of the new buses ordered as of January 2002 are natural gas powered.[16]

Table 9.
Estimated U.S. Growth of NGV populations in the heavy-duty vehicle sector

Type of Heavy-Duty Vehicle	1996	2002	Growth
Buses (Transit, School, Others)	1,800	6,300	320%
Medium-Duty Trucks	4,600	8,500	89%
Heavy-Duty Trucks	400	3,000	650%

Source: adapted from information provided by the GTI Infrastructure Working Group and the Natural Gas Vehicle Coalition

In both numbers of vehicles and volumes of petroleum fuel displaced, CNG continues to be the predominant fuel for NGVs in California. Several large transit districts in California (e.g., MTA) are operating large numbers of CNG buses and displacing very significant volumes of diesel fuel, as noted above. In addition, many “niche markets” for CNG have emerged in applications such as taxicabs, school buses, package delivery and shuttle buses.

LNG is gradually beginning to displace diesel as the fuel for certain heavy-duty applications, including grocery distribution, refuse hauling and public transit (see Figure 3-1).

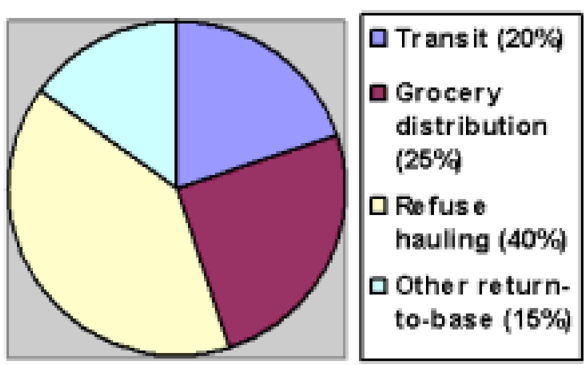
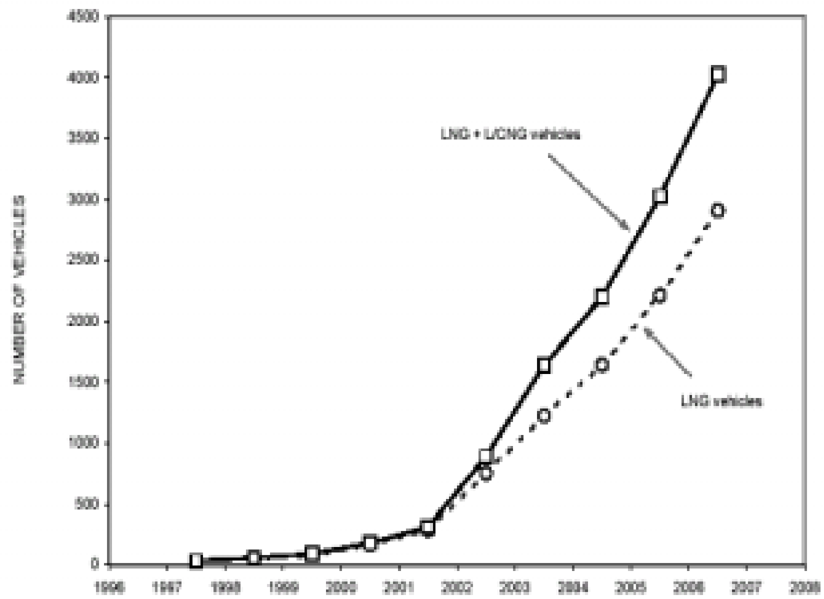


Figure 3-1. Estimated Distribution of LNG Vehicles in California (ADLittle for DOE/GTI)

In mid 2001, there were an estimated 575 LNG vehicles operating in California or under immediate procurement plans.[17] The 2001 version of this report cited various sources in estimating that a rapid increase in these numbers would occur in California over the next several years. A more recent and detailed study for the Energy Commission[18] estimates that by 2008, approximately 3,100 vehicles in California will be running on LNG, and another 1,100 CNG vehicles will obtain fuel at LNG stations (in the form of L/CNG; shown as "L/CNG Vehicles"). Figure 3-2 shows these projected growth curves.



Source: USA Pro & Associates and St. Croix Research (see footnote 18).

Figure 3-2. Projected Growth for California NGVs Needing Fuel from LNG Stations

Roughly half of these new LNG vehicles are expected to be transit buses, with heavy-duty trucks and refuse hauler trucks each comprising about 25 percent. Air quality regulations such as SCAQMD's 1190 Series of fleet rules are among the unique drivers in California that are expected to play key roles in expanding the use of such LNG-fueled HDVs (see Table 12 further ahead in this section).

The key differences and opportunities for CNG and LNG vehicles are discussed further in Section 4.1, in the context of infrastructure development.

Vehicle Range and Fuel Economy

Two principal engine types are available for NGVs: 1) spark ignited (dedicated or bi-fuel), and 2) diesel pilot ignited. The real-world driving range for NGVs depends on which engine type is used, and many other factors that include the following:

- Size, weight (including load) and type of vehicle (light-, medium- or heavy-duty),
- Specific application (e.g., transit bus, refuse hauler, shuttle van),
- Vehicle duty and drive cycle,
- Type of fuel used (CNG, LNG),

- On-board fuel storage capacity (volume per tank, number of tanks), and
- Volumetric efficiency of engine.

Because of these many variables and a general lack of verifiable data on AFVs in real-world use, it is difficult to present absolute values for driving ranges of NGVs. The CNG-fueled version of the 2003 Ford Crown Victoria comes with a standard fuel tank holding about 12 GGEs of natural gas, and an optional "extended range tank package" that holds about 17 GGEs. Using the federal fuel economy rating of 15 mpg (combined City and Highway, see www.fueleconomy.gov) for the CNG Crown Victoria, the extended range version will achieve a driving range of 253 miles – about 25% less than the gasoline version of the Crown Victoria. The 2003 Honda Civic CNG vehicle (GX) gets nearly as good fuel economy as its gasoline counterpart, but it stores 8 GGEs of CNG compared to a 13.2 gallon gasoline tank for the standard Civic. The result is a driving range that is about 40% higher for the gasoline Civic. Transit buses powered by CNG engines provide reduced driving range compared to diesel; in some cases special accommodations such as shorter routes or mid-day refueling for CNG buses have been necessary. The most recent models of CNG buses store more fuel and achieve significantly higher range than early versions. Currently, the American Public Transportation Association specifies a minimum range of 350 miles for procurements of new low-floor CNG buses.[19]

Range can be a very important vehicle-selection criterion. It's a primary factor in determining how vehicles can be used, and the routes they can serve, which are especially important issues for fleet managers. Maximizing the range of NGVs (as well as virtually all types of AFVs) is important to achieving their full commercialization potential. Vehicles that provide less than an acceptable range are likely to be relegated to restricted use in "niche" applications that ultimately may not significantly advance commercialization efforts for that particular vehicle type and its fueling infrastructure.[20] However, "acceptable range" can also depend on how a given vehicle is utilized.[21]

For heavy-duty vehicles, the effect of engine efficiency is especially important. As a general rule, field demonstrations of vehicles with spark-ignited heavy-duty natural gas engines have shown an efficiency penalty of about 25 to 30 percent compared to compression-ignited (diesel) engines, while diesel-pilot-ignited natural gas engines are about 5 to 10 percent less efficient then diesel. However, this varies by manufacturer, and new technology is being developed continually. Generally, manufacturers expect to significantly reduce the efficiency penalty of their spark-ignited alternative fuel engines over the next several years, based on continued improvements to their products.[22] Programs are underway with government funding to help major heavy-duty engine manufacturers improve the thermal efficiency of natural gas engines, while reducing emission levels down to the low levels that will be required to meet 2007-2010 standards.

Vehicle and Engine Costs

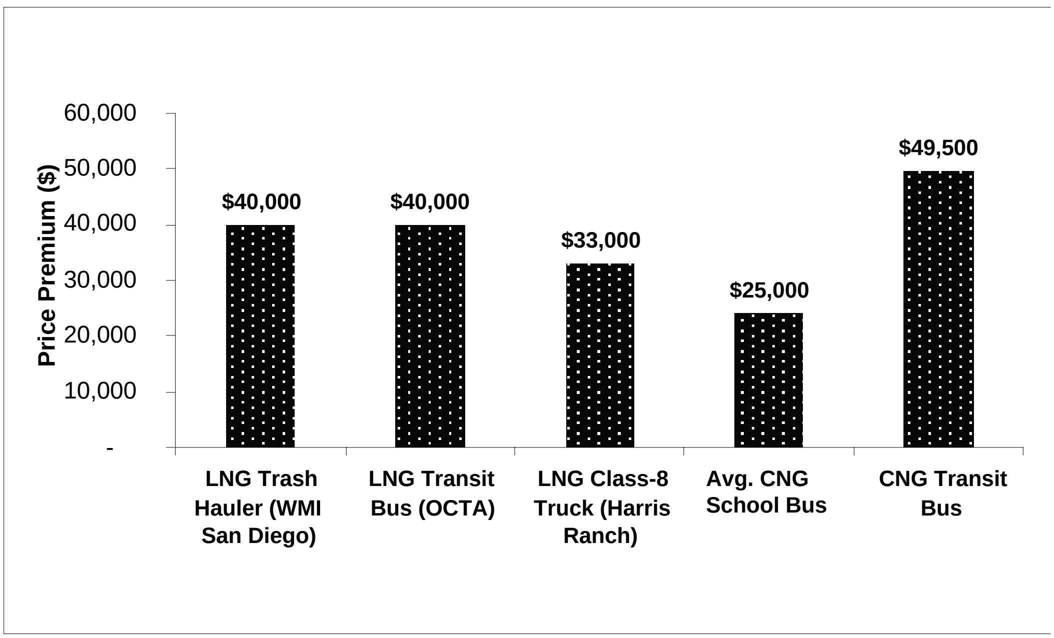
NGVs currently cost significantly more than their gasoline and diesel counterparts. This is largely due to the higher costs of purchasing and installing the on-board fuel-storage systems. Virtually all light- and medium-duty NGVs run on CNG, requiring on-board storage of compressed gas in high-pressure cylinders. These CNG tanks are manufactured from steel, fiberglass-reinforced steel, fiberglass-reinforced aluminum or 100 percent composite materials. Because they are currently designed[23] for working pressures of 3,000 or 3,600 psi, CNG tanks are much heavier and more expensive than gasoline or diesel fuel tanks per amount of energy stored.

Table 10 lists the approximate incremental costs of several commercially available light- and medium-duty CNG vehicles.

Table 10.
Incremental cost of selected light- and medium-duty CNG vehicles

Light- / Medium-Duty CNG Vehicle	Approximate Incremental Cost
Honda Civic GX	$4,500
Dodge Ram Van 2500	$7,800
Ford E-Series Van	$5,000 to $6,000

Source: Edmunds.com and manufacturer literature



Sources: survey input, Carl Moyer program applications, and discussions with manufacturers, etc.

Figure 3-3. Incremental cost (over diesel version) of selected heavy-duty NGVs

As noted, heavy-duty NGVs are commercially available in both CNG and LNG configurations. The total incremental cost of such vehicles typically ranges from about $24,000 to $50,000. The engine component of this differential cost is typically about $15,000 to $20,000, regardless of whether CNG or LNG is the fuel. However, heavy-duty CNG vehicles usually have a higher price premium than LNG vehicles using the same engine. For example, Figure 3-3 indicates that the incremental cost of an LNG-fueled transit bus is about $9,500 less than the incremental cost of an equivalent CNG-fueled transit bus. This is largely due to the higher cost of CNG storage on an energy equivalent basis. Still, on-board storage of LNG is expensive; a typical LNG truck fuel storage system configured with two cryogenic 119 gallon LNG tanks costs about $20,000 ($6,000 per tank, plus installation). A diesel fuel tank with capacity to carry the same amount of energy is significantly less expensive. Fortunately, activities are underway to solve problems with on-board LNG storage tanks, and new tank designs are under development.[24]

Although heavy-duty natural gas vehicles cost significantly more than comparable diesel vehicles, most use engines that are certified to one of the CARB's Optional Low-NO_x Emission Credit Standards. As a result, over the last several years fleets have been eligible to receive funds from various sources (e.g., the Carl Moyer Program and AB 2766) to offset the higher capital costs of these engines.[25] Current engine price premiums are largely a function of low manufacturing volumes. For example, a representative of Cummins Engine Company indicated that the incremental cost of its commercially available heavy-duty natural gas engines would be significantly reduced if sold in larger volumes, and these engines could cost less than their diesel counterparts if sold at equivalent volumes.

Advanced Vehicle Research, Development and Demonstration (RD&D)

Several major programs are underway to improve the commercial viability of natural gas vehicles, especially in the heavy-duty sector. These programs involve a wide variety of public and private entities, but all are basically designed to address the following parameters: 1) improve performance, power density and efficiency, 2) further reduce emissions, 3) reduce cost, 4) broaden product offerings, and 5) improve on-board fuel storage options and increase energy volumes. Table 11 summarizes some of the major existing RD&D efforts involving natural gas vehicles, which are designed to address these needs.

Table 11.
Examples of efforts to improve heavy-duty NGV commercial viability

Name of RD&D Program	Participants	Major Program Objective(s)	Timeframe
Next-Generation Natural Gas Vehicle	Government-industry consortium headed by DOE-NREL, with 33 other agencies / companies / organizations	Design, develop, and evaluate prototype high-efficiency NGV platforms for: • Class 3-6 CNG (MDV) • Class 7-8 LNG (HDV)	Build prototype Class 3-6 CNG and Class 7-8 LNG vehicles by 2004
Low-NOx Heavy-Duty Natural Gas Engine Program	Energy Commission, DOE-NREL, SCAQMD, Cummins Engine Company, Westport Innovations, Inc., Detroit Diesel Corporation	Develop, certify and commercialize heavy-duty engines at or below 0.5 g/bhp-hr NOx	Certify engine by late 2002 or early 2003, as part of NGNGV program
Dedicated LNG ISX-G and ISM-G Engines for Class 8 Trucking	Cummins Engine Company, Westport Innovations, Inc.	Demonstrate low-NOx LNG trucks with 15-liter ISX-G engine in California and Canada	Production 400 - 450 HP ISX engine by 2004; 280 – 370 HP ISM engine by 2005

Projection of NGV Populations by 2007

Based on existing regulatory drivers and incentive programs, and the number of commercial offerings available, there will be high demand for natural-gas-powered HDVs in California for at least five years, and possibly beyond. Regulatory drivers include CARB’s Transit Bus Fleet Rule and the South Coast Air Quality Management District (SCAQMD) “1190 Series” of fleet rules. Table 12 lists SCAQMD’s adopted or proposed fleet rules affecting HDVs. This table indicates that roughly 16,000 new HDVs to be purchased under five fleet rules will be candidates for alternative fuels. Currently, heavy-duty engines certified to California’s optional low-NO_x credit standard are predominantly fueled by CNG or LNG. However, the actual number and rates of NGVs introduced under these rules will be affected by 1) phase-in rates and exemptions, 2) availability of various engines and vehicles, 3) fleet turnover rates, and 4) available funding for vehicles and infrastructure. Full phase-in of these various rules is expected to occur between 2010 and 2015.

Table 12.
SCAQMD's adopted or proposed fleet rules affecting HDVs

SCAQMD Fleet Rule No.	Targeted Fleet Type(s)	Estimated SCAB HDV Population for Potential Conversion to Alternative Fuels
1192	Transit Buses	5,000
1193	Refuse Haulers	6,000
1194	Airport Support Vehicles	500
1186.1	Street Sweepers	700
1196	Heavy-Duty Public Fleets	4,100
Total		**16,300**

Sources: 1) SCAQMD staff reports on fleet rules, 2) personal communications between Jon Leonard of TIAX and SCAQMD's David Coel (3/27/01) and Larry Irwin (5/6/03).

For transit buses, there is major overlap between the requirements of SCAQMD's Rule 1192 and CARB's Public Transit Bus Fleet Rule. As of November 2002, 68 of California's 75 transit agencies had made a declaration about their chosen "path" to comply with CARB's rule. Forty-two of those 68 selected the diesel path, while 26 selected the alternative fuel path. Based on these declarations, about 2,700 of the 6,800 buses to be purchased under requirements of the rule will be alternative fueled.[26] A majority of those will be natural gas buses purchased by transit districts in the South Coast Air Basin, which must also meet the requirements of SCAQMD's Rule 1192.[27]

For LDV and MDV markets, SCAQMD's fleet rules may not be strong drivers toward NGV purchases, since those rules allow requirements to be met with the lowest-emitting gasoline vehicles. California's recent modifications to the Zero-Emission Vehicle program allow automakers to produce large numbers of "other" clean vehicles as a substitute for ZEVs. Vehicles like Honda's dedicated CNG Civic, which has been certified for the 2003 model year as an Advanced Technology Partial Zero-Emission Vehicle (AT-PZEV), may prove to be cost-effective ways to meet these obligations. However, the same holds true for advanced gasoline vehicles, such as gasoline hybrid-electric vehicles. Meanwhile, unless energy-related regulations such as EPACT are modified to include fuel-use requirements,[28] they are unlikely to stimulate sales of dedicated NGVs or natural gas fuel. In sum, compared to the HDV sector, there is greater uncertainty about the numbers of LDVs and MDVs that are likely to actually use natural gas by 2007, and help expand the CNG (or LNG) infrastructure.

Perspective of the California Natural Gas Vehicle Partnership

In 2002, the NGV industry joined with the SCAQMD and various other government agencies to form the California Natural Gas Vehicle Partnership (the Partnership). The purpose of the Partnership is to further develop the NGV industry in California over the next 10 years, through expansion of vehicle offerings and the natural gas fueling infrastructure. The Partnership has established very aggressive goals for market penetration of NGVs in the state over the next decade, as shown in Table 13.

Table 13.
Projections of California's NGV Populations by 2013

Parameter Projected	Light-Duty NGVs	Heavy-Duty NGVs
Estimated total NGVs in California today	16,000	4,000
Projected number of NGVs in California by 2013	500,000	100,000
Average annual increase needed to achieve projection	41%	38%
Source: Michael Eaves, California NGV Coalition, presentation to the California NGV Partnership, February 20, 2003.		

The vehicle projections in Table 13, which were developed by members of the Partnership representing engine and vehicle manufacturers, estimate the magnitude of NGV deployment that will be needed for manufacturers to achieve economies of scale, thereby reducing production costs to sustainable levels.[29] Members of the Partnership acknowledge that these NGV penetrations are aggressive. Major improvements to and expansions of the natural gas fueling infrastructure will be required, in tandem with a ramp-up of vehicle production levels and other factors (e.g., new fleet incentives and/or regulations). The associated infrastructure requirements and activities are described in Section 0.

3.1.2 LPG (Propane) Vehicles

LPG (also known as "propane," in reference to its primary constituent) has long been one of the most widely used alternative fuels, including use in the transportation sector. Worldwide, it is estimated that 2.5 million vehicles use LPG fuel; about 500,000 of these are located in the United States. Commercial fleets in applications such as pickup trucks, taxis, buses, airport shuttles, and forklifts operate approximately 60 percent of the LPG vehicles in the United States. [30]

Commercially Available Vehicles / Technological Maturity

Commercial offerings of LPG-fueled cars and light trucks have largely been limited to bi-fuel vehicles, which can run on either LPG or gasoline using the same engine but separate fuel systems. As is the case with similar natural gas engines, bi-fuel propane engines are convenient to the fleet operator, but they don't allow optimization for the low-emissions combustion characteristics of LPG. The California Department of Transportation (Caltrans) operates a large fleet of Ford F-150 bi-fuel LPG pickups, and has joined with the Department of General Services to significantly increase the use of propane in those vehicles.[32] Under the Energy Commission's Alternative Fuel Infrastructure Program, up to 13 new propane stations are being installed to help Caltrans achieve this (see Section 4.2).[33]

However, the lack of dedicated, low-emissions vehicles and engines offered by major vehicle manufacturers continues to be a barrier for propane as a major transportation fuel. In the light- and medium-duty sector, no low-emission propane vehicles are listed on the California Air Resources Board website as being commercially available in California for the 2003 model year.[34] However, members of the propane industry indicate that at least two medium-duty Ford vehicles (E450 and F450/550 pickups) with dedicated propane, 6.8 liter V-10 engines have been certified to the Ultra-Low-Emission Vehicle (ULEV) standard.[35] For the 2002 model year, several types of medium-duty propane vehicles with GM's 5.7 liter engine were certified to the ULEV standard, using fuel-induction technology from Quantum Technologies (see Table 14).

Table 14.
2002 MY medium-duty LPG low-emission vehicles available in California

Manufacturer	Model(s)	Fuel	Emission Certification
GMC / Chevrolet	G2500 Express, G3500 Express and Van, Savanna Cargo, Savanna Passenger Van	Dedicated LPG	ULEV

Source: California Air Resources Board, "Buyers Guide to Cleaner Cars," updated May 2003, (www.arb.ca.gov/msprog/)

For heavy-duty applications, at least two dedicated LPG engines have been certified to California's heavy-duty optional low-NO_x credit standards (see Table 15). These are among the lowest-emitting heavy-duty engines available in the world, and can work in a variety of medim-heavy duty applications (on-road and off-road). For example, the Cummins B5.9 LPG Plus engine is a versatile powerplant that can be used in a variety of medium heavy-duty applications. These include large pickups; small school buses; vehicles operated by transit properties including shuttle buses; step vans; delivery trucks; and port vehicles such as yard hostlers. The B LPG Plus version of the B5.9 engine (195 hp) is available throughout North America, and there are significant numbers in revenue service for these types of applications.[36]

Table 15.
Recent H-D dedicated LPG engines certified to Low-NO_x Standards

MY	Manu-facturer	Service Type[a]	Fuel	Displace-ment (ltr)	NOx (g/bhp-hr)	PM (g/bhp-hr)	Cert. Std. NOx	HP
2002	GFI	MHD	LPG	6.8	1.5	--	1.5	310
2002 2004	Cummins	MHD	LPG	5.9	2.5 NOx plus NMHC	0.06	2.5	195

[a]Service Type: MHD (Medium Heavy-Duty 8,500 to 26,000lb. GVWR)
Source: California Air Resources Board website and Executive Orders

Other heavy-duty LPG options include certified after-market kits, which also provide low NO_x emissions.

Vehicle Range and Fuel Economy

A gallon of propane contains about 71 percent and 65 percent respectively, of the energy found in a gallon of gasoline and diesel. Like their natural gas counterparts, dedicated propane engines use spark ignition and can achieve similar fuel efficiency to gasoline engines. However, spark-ignited alternative fuel engines are significantly less fuel efficient than diesel engines, which use compression ignition under a "leaner" (higher air-fuel ratio) combustion process.

A typical medium-duty dedicated propane vehicle holds about 15 gallons of fuel, in a single tank weighing about 138 pounds and taking up 2.0 cubic feet of space.[37] The range for this type of vehicle would be about 150 miles. The 2002 dedicated LPG version of GMC's Express and Savannah vehicles (medium-duty pickups and vans) holds 29 LPG gallons in the stock fuel tank. This provides a range of about 250 miles[38] – generally adequate for the fleet niche they typically serve. Heavy-duty vehicles that use dedicated LPG engines (i.e., the Cummins 5.9 LPG engine) are often used in shorter-haul, on-road applications (e.g., school buses) or off-road applications (e.g., yard hostlers); in part, this is due to their diminished driving range compared to comparable diesel vehicles.

Options are available to add one or more additional fuel tanks to LPG vehicles, thereby achieving about the same energy storage (and range) of an equivalent gasoline vehicle. The tradeoff is increased vehicle weight, which lowers vehicle fuel economy and can impact performance. In addition, cargo space may be slightly compromised.

Vehicle/Engine Cost

The costs and prices of LPG vehicles are similar to those of CNG vehicles, although onboard LPG fuel tanks are less expensive than CNG tanks. Light- and medium-duty LPG vehicles are typically priced about $4,000 to $5,000 more than the gasoline vehicles from which they are derived. The incremental cost for a shuttle bus with the Cummins B5.9LPG engine is approximately $15,000. Higher costs of the B5.9LPG engine due to low-volume production have been a significant barrier to deploying greater numbers of this extremely clean, dedicated LPG engine.

Advanced LPG Vehicle RD&D

Some activities are reportedly underway by manufacturers to develop advanced LPG vehicles. These include efforts between General Motors and GFI Control Systems to develop LPG fleet vehicles for use as police cars and taxicabs. Also, a front-engine conventional school bus on a GM chassis may be introduced into the market in the near future, with a dedicated propane version of the John Deere 8.1 liter engine.[39] Other potential low-emission LPG platforms include various types of medium-duty trucks, and full-sized pickup trucks, passenger vans, and cargo vans.

In 2001 it was reported that the DOE is working with one or more auto manufacturers to develop an advanced, dedicated LPG vehicle fully optimized for low emissions and high performance (high range and power, etc.). No new information is available on this effort, and the time frame for potential commercial introduction of such vehicles remains unknown. The Los Angeles Department of Transportation has recently completed the initial phase to demonstrate two hybrid-electric transit buses powered by LPG-fueled Capstone microturbines. These hybrids have basically performed well in revenue service on typical LADOT bus routes, although they have been operated fewer hours per day than diesel buses. Additional, more rigorous testing is planned by LADOT. The potential for this type of advanced powertrain to lead to wider use of LPG in key heavy-duty vehicle applications still exists.[40] In the recent past, Orange County Transit Authority has considered deploying LPG hybrids with dual 75 kW Capstone microturbines, to make use of its existing onsite propane stations.[41]

Projection of LPG Vehicle Populations by 2007

Beyond its use in bi-fuel vehicles – which often end up being operated mostly on gasoline – LPG continues to have good potential to become a more mainstream low-emission transportation fuel offering compelling societal benefits. It has proven to be an exceptionally clean-burning fuel in dedicated heavy-duty engines, and greater deployment could yield both significant emission reductions and major displacement of gasoline and diesel fuels. A significant challenge involves getting major vehicle and engine manufacturers to build dedicated LPG platforms that are affordable and optimized for the fuel's excellent combustion characteristics. This appears to be underway, to a limited extent.

It's difficult to estimate the number of LPG vehicles that are likely to be on the road by 2007 in California. In part, this depends on what role bi-fuel vehicles will continue to play. The reported decision by Caltrans to routinely begin operating its large fleet of bi-fuel F-150 pickups on propane is a very positive step in the right direction. Teaming with the Energy Commission to deploy up to 13 new propane stations, Caltrans appears on the verge of displacing large volumes of gasoline through use of LPG in its bi-fuel fleet. Still, there are no strong energy-related drivers or incentives that make use of AFVs compelling to fleet operators, as a general rule. Air-quality drivers such as SCAQMD's fleet rules and CARB's modified ZEV rule may help deploy dedicated propane vehicles, but that will depend on the degree to which vehicle and engine manufacturers commit resources to this particular fuel / technology combination.

3.1.3 Electric Vehicles

In 1990, CARB adopted the ZEV program, which effectively required that 10 percent of all new cars offered for sale in California by 2003 would be powered by battery-electric propulsion systems.[42] Over the last decade, CARB has conducted biennial reviews of the program, resulting in significant evolution of the program's original "ZEV mandate." In 1996, CARB agreed to eliminate the 1998-2002 ZEV requirements in exchange for agreements with the six largest automakers to produce a very limited number of "demonstration" EVs in California. All automakers complied with this agreement, but some refused to continue producing EVs, while others produced small numbers to earn ZEV "credits" against their 2003 obligations. Although the production numbers for these full-function battery EVs was small, all vehicles were leased or sold to consumers and fleets, and demand for EVs exceeded supply. Some automakers began focusing their EV-related efforts on developing low-speed "neighborhood electric vehicles" (limited to 25mph maximum).

In January 2001, CARB adopted major amendments that were designed to "maintain progress towards commercialization of ZEVs while recognizing the market constraints created primarily by the cost of battery technology." Essentially, these amendments reduced the numbers of ZEVs to be required in the near term, and broadened the scope of alternative vehicle technologies that manufacturers could utilize in meeting their ZEV obligations.[43]

In April 2003, CARB again voted to modify the ZEV regulation. Acknowledging that the ZEV regulations were "on hold for 2003-2004 because of automaker lawsuits," CARB adopted changes designed to go into full effect by 2005.[44] The most significant change is the creation of "a new ZEV pathway" that offers manufacturers a choice of two options for meeting ZEV requirements. The first option is for automakers to meet standards similar to the ZEV rule as it existed in 2001. This means producing a vehicle mix that includes 2 percent pure ZEVs, 2 percent "advanced-technology" partial ZEVs (including hybrid-electric vehicles and CNG vehicles), and 6 percent partial ZEVs (PZEVs), which are simply very low emission gasoline vehicles. The second option is for automakers to accept a new "alternative" ZEV compliance strategy that includes producing sales-weighted numbers of fuel cell vehicles, starting with up to 250 in 2008, but increasing to as many as 50,000 fuel cell vehicles by 2017. Under this option, automakers can substitute battery EVs for up to 50 percent of their fuel cell vehicle requirements.[45] And under both options, smaller numbers of battery EVs can substitute for PZEVs or "advanced technology" PZEVs.

In addition, CARB announced that it may appoint "an independent review panel of technology/industry experts with no financial ties to motor vehicle manufacturers." This panel will be chartered with reporting on "ZEV technology progress, costs and consumer acceptance." CARB staff will continue to report annually on the progress of the ZEV program.

In adopting these amendments, CARB reiterated the need to "maintain pressure on the commercialization of ZEV technologies," while essentially acknowledging the industry's position that *current-technology* full-function battery EVs are still too expensive and technologically immature. As in previous amendments, CARB attempted to give automakers greater flexibility in meeting individual requirements, while still requiring that equivalent overall emission reductions will be achieved.

In the most recent amendments to the ZEV regulations, CARB did provide substantial regulatory incentives for "plug-in" hybrid electric vehicles. Such vehicles will operate like today's gasoline electric hybrids, except they will be equipped with a somewhat larger battery pack and the ability to recharge the batteries from a standard 110 volt outlet. Plug-in hybrids are expected to have a "pure-electric" (zero emission) driving range of 20 to 60 miles before the internal combustion engine becomes operational. According to the Electric Power Research Institute (EPRI), using electricity from the grid to recharge these vehicles can reduce emissions of criteria pollutants and greenhouse gases by up to 60 percent even when compared to today's low-emission hybrids, and petroleum consumption can be cut by 75 percent.[46] EPRI has initiated a three-phase research and development program to build and test prototype plug-in hybrids in the 2005 time frame. In an effort sponsored by EPRI along with a Federal Transit Administration consortium, Kansas City has been selected as the first test site for a plug-in hybrid electric transit bus with an all-electric range of 20 miles.[47] As of mid 2003, no manufacturer had been selected to build the bus.

It is noteworthy that significant numbers of non-road EVs are being operated in California, including forklifts, golf carts, tow tractors, airport ground support equipment, burden and personnel carriers, turf trucks, sweepers, scrubbers, and varnishers. Today there are approximately 300,000 of these non-road electric vehicles, with a combined electrical load of more than 800 megawatts. Populations of these vehicles are increasing due to both regulatory and market forces. In addition, heavy-duty buses powered by battery-electric propulsion systems are being operated in cities such Santa Barbara and Chattanooga, Tennessee.

Commercially Available Vehicles / Technological Maturity

As recently as 2001, 12 light- and medium-duty on-road EV models were reportedly available for lease or sale in California.[48] Six major automakers (General Motors, Ford, Daimler Chrysler, Toyota, Nissan, and Honda) had produced about 4,100 of these "pure ZEVs" for the California market, as of early 2000.[49] Under the terms of agreements signed between CARB and certain automakers, many of these EVs were equipped with advanced batteries.

Since that time, efforts by the major automakers to develop and commercialize battery EVs have reportedly been reduced to their lowest levels in several years. In terms of technological barriers, high manufacturing costs and limited performance of storage batteries have been most commonly cited. Despite focused programs to develop and demonstrate advanced battery technologies over the last few years, CARB staff reported at the March 2003 biennial review that "no significant reductions in the cost of battery EVs" have been realized with the small numbers of vehicles produced to date. The staff report further noted that "the marketing of battery EVs has been met with only modest success," citing only neighborhood electric vehicles (NEVs) as achieving "limited usage" commercialization. Staff found that the plans of automakers regarding on-road battery EV development "have slowed or even halted."[50]

As of mid 2003, it is believed that approximately 2,300 EVs are registered in California for on-road use, not including smaller "neighborhood electric vehicles" known as NEVs. However, only one of the six automakers that leased or sold battery EVs in California continues to make EVs available.[51] The highest-profile, and costliest EV program, General Motors' EV-1 leasing effort, was terminated in early 2002. Informing its customers that the "costs of maintaining the EV-1 fleet substantially outweigh the benefits," GM announced that it was "no longer considering offering any future fleet of EV-1 vehicles."[52] Toyota announced that it "discontinued production of the RAV4 Electric Vehicle worldwide in the spring of 2003," and "therefore will no longer take orders" for EV products. For any RAV4s still in service, Toyota "ensured" customers "that dealers capable of servicing RAV4 EVs" would continue to be located "in each major metropolitan area in California throughout the 5-year powertrain warranty period."[53] Other major automakers made similar announcements about the cancellation of their EV programs.

The implications to California's EV charging infrastructure are discussed further below.

Vehicle Range

A significant shortfall of current-technology battery EVs has been their reduced driving range compared to conventional vehicles. Reduced range is a direct function of the relatively low energy density (quantity of energy stored per volume) provided by EV batteries. The Nissan Altra EV, which uses advanced lithium-ion batteries that achieve among the highest energy densities (90 watt-hours per kilogram), provided a maximum driving range of about 120 miles when tested by Southern California Edison.[54] This range can be considered best case -- Nissan advertises a "real-world" driving range of 80 miles for its Altra EV.[55]

Reduced range is one of the key reasons why CARB has established very modest market goals for battery EVs. The concept was that these limited numbers of vehicles could primarily be used in "niche" applications during the early stages of commercialization. Market research conducted by UC Davis and others has indicated that even with limited range, between 12 and 18 percent of new car sales could be EVs if the vehicles were produced in body styles that consumers wanted and were priced comparably to conventional gasoline vehicles.[56]

Reduced range is also an important reason why EPRI and the electric utilities industry are interested in plug-in hybrid vehicles. They believe strong potential exists for plug-in hybrids to provide driving ranges and refueling times that are similar to gasoline (or diesel) hybrids -- while offering the compelling environmental benefits of pure-electric vehicles. They note that plug-in hybrids can be used in virtually any size or type of vehicle, including SUVs and transit buses. According to the California Electric Transportation Coalition, plug-in hybrids "are mass-market vehicles that can provide benefits to all consumers and markets" that "may be the next generation of advanced technology" for on-road applications.[57]

Vehicle Cost

During CARB's 2001 ZEV regulation review, various estimates were reported about the costs to manufacture EVs in small and large volume productions, and the expected price that consumers would pay in the 2003 time frame. Not surprisingly, estimates cited from the battery industry and proponents of the ZEV regulation differed significantly from those of the auto industry. However, most parties agreed that battery-electric EVs will cost significantly more to manufacture than conventional vehicles, at least until high-volume production levels and technological advancements are realized. The main cause cited for higher EV costs were expensive battery packs. Although an expert battery panel found that significant cost reductions could be expected over the next decade,[58] CARB reported in early 2003 that "no significant progress has been made in reducing the costs of advanced EV batteries." Thus, the economics of manufacturing and selling commercial full-function battery EVs in California remain very clouded.

The costs of plug-in hybrids are expected to be significantly lower than full-function battery EVs. This is because hybridization allows the battery packs to be significantly downsized. According to EPRI research, plug-in hybrids could be less expensive than conventional gasoline vehicles on a life-cycle cost basis, if produced in traditional automotive-scale volumes.

Non-road electric vehicles (e.g., forklifts) are generally priced comparably, or less than, similar vehicles using combustion engines.[59] Some of these vehicles operate in enclosed areas not suited for combustion engines.

Advanced Electric Vehicle RD&D

By many accounts, advanced RD&D efforts within the auto industry have shifted away from full-function battery EVs in favor of hybrid electric vehicle or fuel cell vehicle technologies that also feature electric drive, such as fuel cell vehicles or hybrid electric vehicles. Fuel cell vehicles are discussed in Section 3.2. Hybrid electric vehicles are further discussed in the section immediately below.

Projection of Electric Vehicle Populations by 2007

In the 2001 version of this report, it was noted that the timeframe for full (self-sustaining) commercialization of battery EVs will probably be a function of two key factors: 1) regulatory stability, and 2) the relative costs and benefits of EVs versus other propulsion technologies. Since that time, both factors have come into play to interject new uncertainty about battery EV commercialization. Hence, it's very difficult to estimate the number of battery EVs that will be on the road in California by 2007. With each change of the ZEV regulation over the last decade, automakers have gained increased flexibility to comply through the use of other advanced vehicle technologies. Gasoline-fueled hybrids are emerging are leading options for automakers to commercially deploy in greater numbers.

Hybrids offer the advantages of electric drive (high torque and increased efficiency at low speeds) while providing performance and range equivalent to, or better than, conventional vehicles. America's first commercial hybrid was Honda's two-door Insight, introduced for the 2000 model year and rated at 61 mpg (city) and 70 mpg (highway). For the 2001 model year, Toyota introduced its four-door Prius hybrid; a more main-stream passenger vehicle that achieved EPA fuel economy ratings of 52 and 48 mpg for the city and highway, respectively. For the 2003 model year, Honda commercialized its four-door Civic Hybrid. The result is that for the 2003 model year, three different hybrid models are available for purchase, each of which has a combined EPA fuel economy rating of at least 48 mpg. As of early 2003, both Honda and Toyota are reporting record sales of their hybrid models,[60] and a number of new hybrid models (including pickup trucks and SUVs) have been announced from several different manufacturers for the 2004 model year. These vehicles are already being certified to near-equivalent ZEV emission levels, and they provide very significant reductions in gasoline usage compared to similar conventional vehicles. According to the CARB staff report, within a decade or less hybrids will be *less costly* to own and operate than conventional vehicles on a life-cycle basis.[61]

Commercially available hybrids do not use alternative fuels or charge from the electricity grid; consequently, no new fueling infrastructure deployments will be required as greater numbers of these vehicles are introduced into the market. Over the longer term, however, hybrids may be introduced that use clean fuels and/or charging from the grid. The infrastructure implications of such technologies will likely be similar to today's vehicles that use clean fuels or EV charging stations.

3.1.4 Ethanol-Fueled Flexible Fuel Vehicles

Commercially Available Vehicles / Technological Maturity

Flexible-fuel vehicles (FFVs) capable of operating on ethanol use a blend of 85% ethanol and 15% gasoline (known as "E85"), or any mixture of E85 and gasoline.[62] Major manufacturers have sold E85 FFVs in California and other states for several years. Table 16 lists the 2003 model year E85 FFVs. Similar offerings have been available over the last few model years. According to DMV records, there are currently 172,000 E85 FFVs registered in California, and the numbers continue to grow. On the heavy-duty vehicle side, several hundred "neat" ethanol (E95 or E100) transit buses were operated by the Los Angeles County Metropolitan Transportation Authority in the mid-1990s. However, those particular buses were either retired or repowered with diesel engines, due to higher fuel and maintenance costs, as well as a lack of product support from the bus and engine manufacturers.

Table 16.
Examples of 2003 model year E85 FFVs available in California

Manufacturer	Available Models as E85 FFVs
GMC / Chevrolet	Various SUVs (Tahoe, Yukon, Suburban) and pickups (Silverado, GMC Sierra)
Chrysler / Dodge	Various minivans; Sebring and Stratus sedans / convertibles
Ford / Mercury	Taurus sedans; Sable wagons; Explorer and Mountaineer SUVs; Ranger pickups
Mazda	3.0L V6 B3000 pickups

Source: National Ethanol Vehicle Coalition website (www. E85fuel.com/ffvs.htm)[update reference]

Range and Fuel Economy

E85 is a relatively high-octane fuel that contains about three fourths as much energy as gasoline (approx. 82,000 Btu per gallon). When driven on E85, this translates to a proportional reduction in driving range (assuming the same size fuel tank) for FFVs compared to similar gasoline-powered vehicles. Estimates for mid-sized vehicles indicate that more than 350 miles can be driven on an 18-gallon tank of E85 fuel. FFVs operating on E85 get a horsepower boost of approximately 5 % -7 %.[63]

Vehicle Cost

The FFV feature comes standard on most (or all) of the vehicles shown in the table above. As such, there is no incremental capital cost price increase to the consumer for this capability to operate the vehicle on E85.

Projection of Ethanol Vehicle Populations by 2007

FFVs that are designed for operation on E85 are already commercially available, as noted above. By the end of 2003 the projected E85 FFV population is expected to be around 220,000.[64] Wide commercial availability of the E85 FFV feature on popular light-duty models is expected to continue as long as automakers are motivated by the Corporate Average Fuel Economy (CAFÉ) benefits received from selling the FFVs. Thus, as further discussed in Section 4.4, tremendous *potential* exists to displace gasoline by fueling California's growing fleet of FFVs with E-85.

Future developments to market more advanced ethanol-fueled vehicles are unknown. No major automobile or HDV manufacturer has announced plans to commercialize dedicated ethanol vehicles (E85 or E100) in California. Like methanol, ethanol can be used as a carrier of hydrogen for fuel cell vehicles (see section 3.2.1), although on-board reforming of ethanol presents greater technical challenges than methanol. Some manufacturers of reformer systems are working on "multi-fuel" reformers that reportedly include the capability to use ethanol. However, no information is available regarding any definitive plans by vehicle manufacturers to pursue this option on their fuel cell vehicles. Thus, prospects appear low for dedicated ethanol vehicles to be commercially available in California over the next five years.

3.2 Longer-Term Fuel / Vehicle Technologies

The California Alternative Fuel Infrastructure Program acknowledges that certain not-yet-commercial fuel and vehicle technologies have significant potential to displace petroleum fuels within the next decade, and provide emission reductions. Among the options included here are advanced internal combustion engine vehicles and fuel cell vehicles using neat methanol (M100) or hydrogen. In particular, fuel cells[65] using methanol and hydrogen fuel have potential to play roles in meeting California's needs for zero- or near-zero-emission vehicles. However, these fuels can also work well in advanced internal combustion engine vehicles, while providing extremely low emissions. The following sections focus on the use of methanol and hydrogen in fuel cell vehicles, but the same infrastructure issues and barriers apply for internal combustion engine (ICE) vehicles using these fuels.

Fuel cells offer the advantages of batteries because they derive power from electrochemical reactions (i.e., no combustion) and utilize electric propulsion systems. Like engines, fuel cells generate power from an on-board fuel that can be rapidly replenished at a fueling station. Thus, they can deliver equivalent range and refueling time. They are capable of operating on a variety of fuels, although many technical and cost tradeoffs exist, and real-world experience on most fuels is very limited.

Several auto manufacturers have announced plans to sell or lease fuel cell vehicles within a decade, and prototype passenger vehicles are now being tested. However, significant technical and cost hurdles must be overcome before these vehicles are likely to become commercially viable, and displace significant numbers of conventional vehicles. Perhaps the biggest hurdle pertains to fuel logistics and infrastructure. Hydrogen is the consensus long-term choice for fuel cell vehicles, because it can provide high efficiency and strong overall environmental benefits (see Section 3.2.2). However, it is also involves the largest capital investments to overcome major technical and institutional challenges. Billions of dollars are invested in California's existing infrastructure for transportation fuels, which accommodates liquids at ambient temperature and pressure. Thus, strong debate continues to occur about the optimal fueling strategy for initial deployment of fuel cell vehicles, and how to make an orderly and affordable transition to hydrogen.

In 1999, CARB and the Energy Commission joined with a collaboration of other government agencies, auto manufacturers, fuel providers, and fuel cell developers to form the California Fuel Cell Partnership. This Partnership has announced plans to begin demonstrating up to 60 fuel cell vehicles (both LDVs and HDVs) in 2003, and some vehicles have already been delivered (see below). Beyond demonstrations, among the first vehicles that will be commercially deployed are transit buses powered by fuel cells (similar to those that are already carrying passengers in public demonstration programs in several North American cities). However, CARB's modification to the ZEV regulation in 2003 offers automakers new options to produce light-duty fuel cell vehicles. Initially, requirements under this compliance strategy are fairly modest -- up to 250 fuel cell vehicles per manufacturer must be deployed by 2008. But, as many as 50,000 fuel cell vehicles per manufacturer could be on the road by 2017.[66]

The following sections describe the status and commercial prospects for fuel cell vehicles fueled by methanol and hydrogen.

3.2.1 Methanol Fuel Cell Vehicles

Technological Maturity

For much of the late 1980s and early 1990s, as many as 15,000 light-duty FFVs powered by M85 were deployed in California. Over the same approximate time period, heavy-duty engines fueled by M100 were used to power nearly 1000 transit buses and heavy-duty trucks in California, as well as numerous heavy-duty trucks. Methanol was sold at many public and private facilities around the state, and methanol-fueled vehicles accumulated tens of millions of miles at its peak use.[67] However, methanol does not play a significant role in California today as an alternative transportation fuel.

This may change because methanol is an excellent carrier of hydrogen for use in vehicular fuel cell engines. Several automakers have investigated the potential to design their fuel cell vehicles to run on methanol, including Daimler-Chysler, Toyota, Honda, GM, Ford, Opel, and Nissan. Currently, the NECAR 5 fuel cell vehicle from Daimler-Chrysler runs on methanol and is being tested in conjunction with the California Fuel Cell Partnership. Other programs are focusing on methanol fuel cells for transit bus applications (for example, refer to the Georgetown University program at http://fuelcellbus.georgetown.edu/). As an Associate Member of the Partnership, Methanex Corporation is helping to coordinate fueling logistics for such demonstration efforts.

On the nearest horizon are systems for fuel cell vehicles that use on-board reforming of methanol to supply hydrogen to the fuel cell engine. Methanol reformers involve the lowest temperature and pressure of any fuel for reforming to hydrogen, thus providing the lowest cost reformer option. For the longer term, “direct methanol” fuel cells are being developed that may offer the advantages of using a liquid fuel without the need for onboard reforming.[68] At the West Sacramento California Fuel Cell Partnership headquarters, methanol (M100) is available and currently being used to fuel the NECAR 5.

Projected Methanol Vehicle Populations by 2010

Little detailed information is currently available about the methanol-fueled fuel cell vehicles that are likely to be deployed in California, and when they will truly be ready for commercialization. It is expected that additional information will be released in the coming year, through the California Fuel Cell Partnership.

3.2.2 Hydrogen Fuel Cell Vehicles

Technological Maturity

Many automakers have launched programs to develop and demonstrate “direct-hydrogen” fuel cell vehicles worldwide.[69] Such vehicles have potential to provide the highest efficiency and fuel economy of any currently known, practicable propulsion technology – while delivering zero-emissions and other environmental benefits. Hydrogen is therefore expected to be the long-term fuel for fuel cell vehicles. On strictly a demonstration scale, in certain niche applications such as transit buses and city fleets, direct-hydrogen fuel cell vehicles are already displacing conventionally fueled vehicles (see Table 17). Much of this work is being sponsored by the California Fuel Cell Partnership, of which the Energy Commission is a member. On the national level, in early 2003 President Bush announced new federal initiatives to support hydrogen fuel cell vehicles.

Table 17.
Examples of direct-hydrogen fuel cell vehicles under development

Vehicle Manufacturer(s)	Fuel Cell Manufacturer	Vehicle Type	Notes / Plans for Commercialization
To be determined	International Fuel Cells	Passenger Car	Under demonstration
Daimler-Chrysler	Ballard / XCELLSiS	Passenger Car	NECAR 2, NECAR 4 (Mercedes A-class)
Ford	Ballard / XCELLSiS	Passenger Car, SUV	Timeframe unknown
New Flyer	Ballard/ XCELLSiS	Transit Bus	1 now being demonstrated at Sunline Transit in Palm Desert
Honda	Celanese Ventures	Passenger Car	FCX in demonstration with City of LA
Hyundai / Impco	Ballard/ XCELLSiS	SUV	Demonstration phase
Mercedes-Benz	Ballard/ XCELLSiS	Passenger Car, SUV/Van, Transit Bus	Timeframe unknown
Nissan	Ballard/ XCELLSiS	SUV	Timeframe unknown
Toyota	Toyota	Passenger Car	Demonstration with Univ. of California, Irvine

Initially, fuel cell vehicles are being deployed in fleet applications to accommodate higher vehicle costs and optimize fueling, operation, and maintenance procedures. To date, the members of the California Fuel Cell Partnership have successfully placed about two dozen hydrogen fuel cell vehicles in California (mostly LDVs, with a few transit buses). The Partnership has announced a goal to place up to 60 new light-duty fuel cell vehicles in California by the end of 2003. The Partnership's transit agency associate partners will begin operating seven full-sized transit buses powered by direct-hydrogen fuel cells in 2004.[70] Several new hydrogen stations are being built to accommodate these vehicles (see Section 4.6).

For heavy-duty applications, hydrogen-fueled buses are being deployed at several transit agencies. SunLine Transit Agency has been among California's most aggressive agency to demonstrate hydrogen buses, placing a hybrid hydrogen fuel cell bus into revenue service in November 2002,[71] with plans to acquire additional fuel cell buses starting in 2004. In 2003, California's larger transit agencies (>200 buses) that have opted for the "diesel path" under CARB's transit bus fleet regulation are required to begin demonstrating at least three Zero-Emission Buses (ZEBs). However, it now appears likely that the ZEBs will not be procured before the 2004-2005 timeframe. By 2008, they will be required to begin purchasing ZEBs (two years sooner than the agencies that selected the "alternative fuels" path).

Among those that have chosen the "diesel path" is AC Transit, which is currently "marshaling resources" to acquire fuel cell buses. To date, government grants amounting to more than $14 million have been procured. By 2004, AC Transit expects to be testing at least three fuel cell buses, which will be fueled at its already-operational (October 2002) hydrogen station onsite at AC Transit in Richmond. If these fuel cell bus demonstrations prove successful, AC Transit plans to make fuel cell buses comprise 15 percent of their acquisitions in 2008.[72] Santa Clara Valley Transportation Authority is another “diesel path” agency planning to conduct fuel cell bus demonstrations over the next few years. The Energy Commission is among various government agencies helping these transit districts to develop the necessary hydrogen-fueling infrastructure (see Section 4.6).

Demonstrations aside, achieving widespread use of direct-hydrogen fuel cell vehicles will require vehicle, fuel-production and infrastructure investments of very large proportions. On the vehicle side alone, major efforts are needed to develop affordable and workable on-board hydrogen storage systems. Even as fuel cell vehicles begin to achieve commercial status, much work needs to be done to educate permitting officials, the general public, and business communities about hydrogen fuel and fuel cell technologies. A significant barrier may be the current lack of hydrogen-specific codes and standards that facilitate safe use of this unique fuel without being overly burdensome or costly to meet.

While the magnitude of the task is large, the planning process for direct-hydrogen fuel cell vehicles and hydrogen fueling stations is currently underway. The Energy Commission has recognized a growing role for hydrogen in meeting the goals and objectives of its Alternative Fuels Infrastructure Program, and has stepped up related activities to support hydrogen technologies. Other government agencies such as CARB, the U.S. Department of Energy, U.S. Environmental Protection Agency, the National Renewable Energy Laboratory, and the SCAQMD are also increasing hydrogen-related activities.[73] These various hydrogen programs are described further in section 4.6.

Vehicle Range and Fuel Economy

Fuel cell engines can operate more efficiently than ICEs, enabling fuel cell vehicles to get more miles from a given amount of energy. Direct-hydrogen fuel cell vehicles are especially efficient, because no on-board fuel reformation process is needed. Also, hybrid electric drive systems offer significant efficiency gains over conventional drive systems, as demonstrated by commercially available hybrid electric vehicles such as the Toyota Prius and the Honda Civic hybrid. As a result of all these factors together, fuel cell vehicles offer improved energy-conversion efficiency. According to the U.S. Department of Energy, a direct-hydrogen fuel cell vehicle operating today converts 40 to 60 percent of the energy in its fuel into engine power, compared to about 30% conversion in today’s gasoline ICE automobiles.[75]

A direct result is that fuel cell vehicles can provide greater vehicle range than would be available from an ICE vehicle using hydrogen. On the negative side, any type of hydrogen-fueled vehicle faces the range constraint of reduced energy content per volume and/or mass of fuel (depending on which form of on-board hydrogen storage is used). However, the high efficiency provided by fuel cells and electric drive offers potential to enable “dramatic” reductions in the weight and size of hydrogen fuel storage systems for future vehicle technologies.[76] Currently, hydrogen fuel cell vehicles cannot achieve equivalent range to comparable ICE vehicles without significant reductions in cargo or passenger space.

The 2003 model Honda Accord sedan powered by a conventional V-6 gasoline engine provides a driving range of about 420 miles.[77] The average range for this class of vehicle is about 340 miles. To demonstrate equivalent (or better) driving ranges, fuel cell vehicles will need advanced on-board hydrogen-storage systems that are yet to be developed and tested in real-world operating conditions. This process is underway, but it's likely to take years or decades of additional development. The federal "FreedomCAR" program led by DOE targets 2015 for successful development of safe and affordable on-board hydrogen storage systems that can provide a minimum range of 300 miles in a fuel cell vehicle.[78] Much of the related development and testing work is being conducted under the California Fuel Cell Partnership's demonstration program, which is expected to provide a growing bank of useful data about vehicle range and performance at least through the current period of funding (2007).

Vehicle Cost

Direct-hydrogen fuel cell vehicles today are generally built by adapting existing LDV or HDV platforms. This requires replacing the conventional engine and transmission with a fuel cell engine and electric-drive system. Automotive fuel cell systems are currently ten times more expensive than internal combustion engines of comparable power.[79] Perhaps the biggest cost challenge is to develop affordable on-board hydrogen systems, which will require lower cost components and containment methods. While compressed hydrogen is typically used in today's prototype vehicles, at least four additional methods are being considered: 1) liquefied hydrogen, 2) selected metal hydrides, 3) refrigerated superactive carbon, 4) carbon or graphite nanostructure technology, and 5) sodium borohydride. The U.S. DOE targets a minimum 80% cost reduction for on-board hydrogen storage by 2015.

The type of electric propulsion system utilized also affects fuel cell vehicle costs. Some manufacturers are building fuel cell electric drive systems that are powered solely by a fuel cell engine, while others are building hybrid drive systems that include a battery pack or some other source for peak power requirements. Hybridization with a battery pack or other energy storage device also enables the use of a regenerative braking system. The choice to hybridize depends in part on the desired vehicle application, e.g., passenger cars or transit buses.

In any case, fuel cell vehicles are virtually "hand built" today and their current incremental cost significantly exceeds that of any other mainstream clean-vehicle alternative. Depending on the type of vehicle and intended application, it currently costs roughly \$2 to \$4 million to build prototypes. With continued progress in fuel cell engine and hydrogen-storage technology, costs for prototype fuel cell vehicles can be dramatically reduced, and volume production will enable further cost reductions. Still, a number of major challenges remain before hydrogen fuel cell vehicles can enter the marketplace at prices comparable to conventional vehicles.[80] Higher operating costs for fuel cell vehicles (e.g., purchasing hydrogen fuel) will also be a major challenge in the early years of commercialization.

Projected Hydrogen Vehicle Populations by 2010

Given the current barriers and uncertainty about demonstration efforts versus actual commercial launches, it's difficult to assess the number of fuel cell vehicles that will be on the road in California over the next 5 to 10 years. Industry leader Ballard Power Systems "expects to meet the commercial launch requirements" of its automotive customers by 2003 to 2005 – the time frame that "most automobile manufacturers have publicly stated their intent to start commercializing fuel cell vehicles."[81] However, recent developments suggest that commercialization will not begin to take place until the 2008 timeframe. CARB has stated that potential exists for hundreds of thousands of fuel cell vehicles to be on the road by 2017, but deployment in 2010 could still be limited to a pre-commercialization scale (roughly, one to two thousand vehicles).

The heavy-duty vehicle sector continues to have at least one regulatory driver: CARB's transit bus fleet rule. While there is considerable uncertainty, a reasonable guess is that up to 20 more hydrogen fuel cell buses will be deployed over the three years from 2008 to 2010.[82] It is possible that fuel cell buses will first be commercially deployed in Europe, where certain factors are more favorable than in the United States (e.g., concerns for global climate change, higher prices of gasoline and diesel). In May 2003, Ballard Power Systems and DaimlerChrysler AG began an effort to road test up to 30 Citaro fuel cell buses in 10 European cities. The first 205-kilowatt direct-hydrogen bus is scheduled to enter service in Madrid, followed by demonstrations in Amsterdam, Barcelona, Hamburg, London, Luxembourg, Porto, Reykjavik, Stockholm and Stuttgart.[83]

Over the longer term (20 years or more), prospects look promising to significantly displace petroleum fuels in California through use of hydrogen fuel cell vehicles. There is little consensus on the exact timeframe, but many public- and private-sector experts believe that direct-hydrogen fuel cell vehicles will gradually replace ICE vehicles as the predominant mode of transportation in metropolitan areas throughout California and the United States. As noted, transit buses are likely to lead vehicle commercialization. A 2003 Delphi market survey of "heavy-duty vehicle industry participants" conducted by WestStart-CALSTART forecasts that fuel cell vehicles will capture 6.3% of the new heavy-duty vehicle market by 2020,[84] most of which would be transit buses. Prospects to accelerate commercialization of light-duty fuel cell vehicles may have recently been increased through CARB's revised ZEV regulation, which includes incentives for automakers to produce tens of thousands of fuel cell vehicles over the next 15 years.

4. Status of the Alternative Fuels Infrastructure in California

The previous section provided an overview of existing clean fuel vehicles in California, as well as those types expected to emerge over the next five years. This helps to lay the groundwork regarding the existing and future demand for a given type of clean fuel. This section assesses the commercial status of the fuels themselves, and their corresponding motor vehicle refueling infrastructure in California.

4.1 Natural Gas Fuel and Fueling Stations

Supply and Price

Regardless of how it is stored onboard vehicles (CNG or LNG), the raw commodity of natural gas must be extracted or produced, then transported to the end user's site (if not produced on site), and prepared for consumption. Two basic forms of natural gas are produced in California: "associated gas" and "non-associated gas." Associated gas is produced along with crude oil, while non-associated gas is not located with oil fields. About 75 percent of the natural gas produced in California is associated gas. In 2001, total natural gas production in California averaged approximately 1.0 billion cubic feet (BCF) per day.[85] The average production in 2000 was approximately 0.92 BCF per day. The lowest year on record for natural gas production in California was 1996, which averaged a production rate of approximately 0.80 BCF per day. [86]

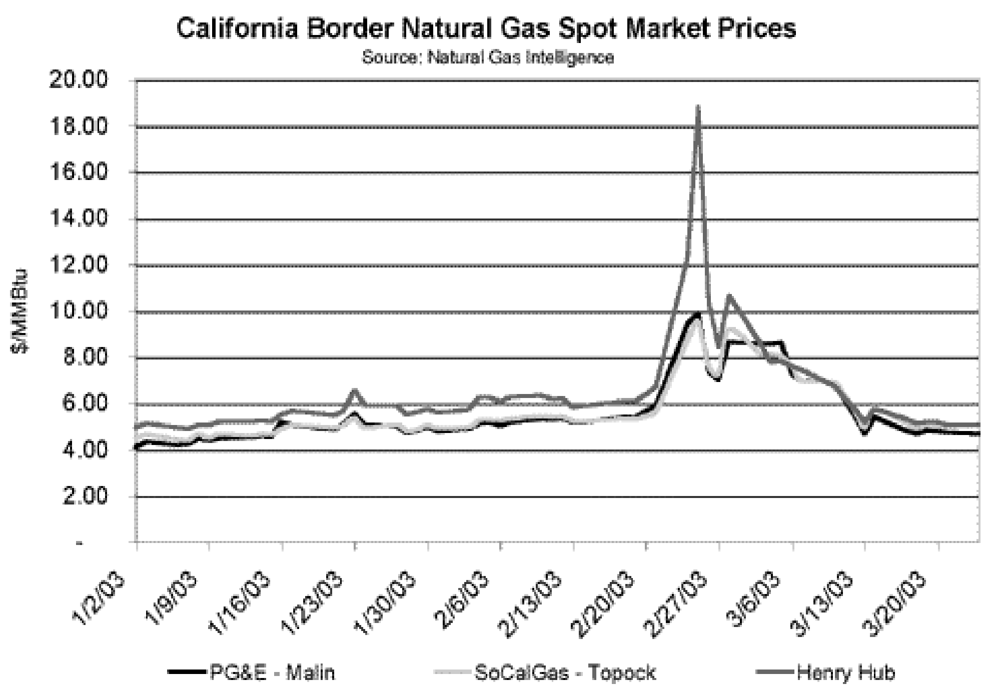
This in-state natural gas production of about 1 billion BCF provides only 15 percent of California's demand. The total volume of natural gas consumed in California was nearly 2,468 BCF in 2001, or an average of about 6.7 BCF per day -- making California second only to Texas among the states in natural gas consumption.[87] This accounts for slightly more than 10 percent of the total U.S. consumption. During peak usage (the winter heating months), as much as 7.5 BCF per day can be consumed in California.

To meet the shortfall of supply versus demand (roughly 1,500 BCF per year), California annually imports major quantities of natural gas from other western states and Canada. Transport into California is mostly accomplished by an interstate pipeline system that, as of early 2001, had a capacity of about 7.1 BCF per day (2,600 BCF annually).[88] With so much of California's natural gas supply dependent on this pipeline system, capacity and operational issues are continually reviewed. In November 2000, an Energy Commission staff report found that "local constraints" on California's natural gas pipeline system can be problematic, but "the physical capacity of interstate pipelines appears adequate, when used in conjunction with in-state storage capability."[89]

Largely in response to the energy crisis of 2000 and 2001, state and federal agencies have expedited efforts to add new pipeline and storage capacity in California. Since early 2001, at least 1.6 BCF per day of new interstate pipeline capacity, and 0.62 BCF per day of intrastate capacity, have been added or upgraded. In-state storage capacity of natural gas has been increased by at least 26 BCF.[90] "Pending" additions that are expected to come on line by 2005 include 1.9 BCF per day of new interstate pipeline (some of which involves converting oil pipelines), and 21.5 BCF of in-state natural gas storage. Also, a number of new liquefied natural gas facilities are being built or planned, which will significantly augment pipeline expansions as a means to increase California's overall supply.[91]

As a commodity in the United States, natural gas is usually priced in dollars per million British Thermal Units (Btu) of energy (abbreviated MMBtu). Over the last decade, prices to end users have been relatively low and stable. However, spot prices began significantly increasing in mid 2000. During late 2000 and early 2001, prices reached all-time highs at more than $49.47 per MMBtu. Among the contributing factors to higher prices were 1) cold weather, 2) high demand (especially from natural-gas-fueled electricity generators), 3) tight supply, 4) lack of recent supply development, 5) lack of alternatives to gas delivered through Topock, Arizona, 6) transport issues (e.g., pipeline limitations), and 7) low storage levels from slow rate of gas injection.[92,93,94] Beginning in mid 2001, prices generally stabilized back down towards a range of $5 to $9 per MMBtu, where they remained for most of 2002 and into 2003 (see Figure 4-1). Despite brief but "dramatic" increases (up to nearly $19 per MMBtu) that occurred at the end of the winter heating season,[95] the spot price of natural gas in California has settled back down to about $3 to $5 per MMBtu entering into mid 2003.[96]

Based on recent trends, further volatility and higher prices for natural gas are likely over the next several years in California. In part, this is because demand in California will increase significantly to alleviate power-generation shortfalls, until major additional electricity generating capacity can be brought on line in California. However, this process is already well underway – in 2002, "emergency action" was taken to expedite permitting and building of new power-generating facilities,[97] including action by the Energy Commission to approve several new natural gas power plants in central and southern California.[98] Combined with increases made to pipeline and storage capacities, and numerous other actions taken since 2001, price increases to California's consumers of natural gas are expected to be "modest" over the near term.[99] Also, near term natural consumption from the transportation sector is not likely to cause a significant impact to the supply of natural gas.



Source: California Energy Commission, "Natural Gas Market Prices, Executive Summary," March 28, 2003.

Figure 4-1. Recent California border natural gas spot prices.

Like natural gas, prices at the pump for gasoline and diesel fuels have also shown significant volatility and reached unusually high levels over the last several years. As Figure 4-2 shows, the price of gasoline (all grades) has rapidly spiked upward over the last 14 months, although a downward trend began in April 2003. According to the Energy Commission, the statewide average retail price of regular gasoline jumped from $1.58 per gallon on January 1, 2003, to a record-setting $2.15 per gallon on March 17, 2003 -- an increase of 57 cents, or 36 percent. As Figure 4-3 shows, similar volatility and price increases have occurred with diesel fuel. In California, the price of diesel fuel increased by as much as 31 cents per gallon over the first quarter of 2003, reaching a statewide average of $1.89 per gallon on March 13, 2003.[100] As with gasoline prices, a clear downward pricing trend can be seen at the start of the second quarter.

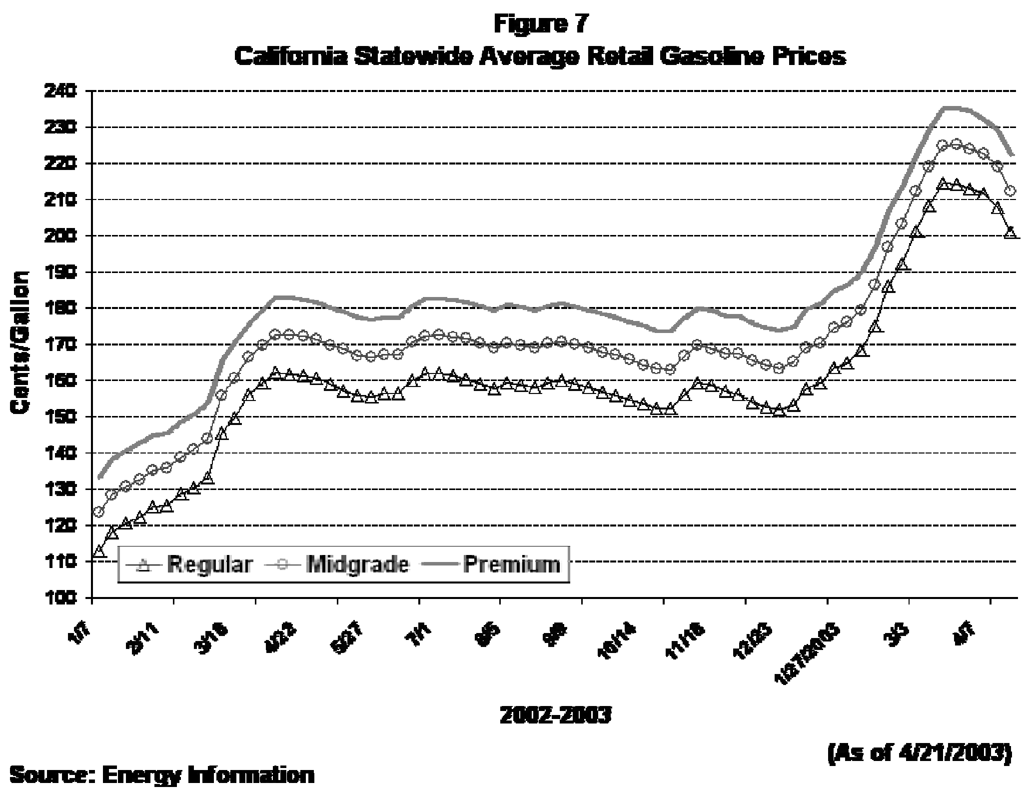


Figure 4-2. California average retail gasoline prices (EIA from www.energy.ca.gov)

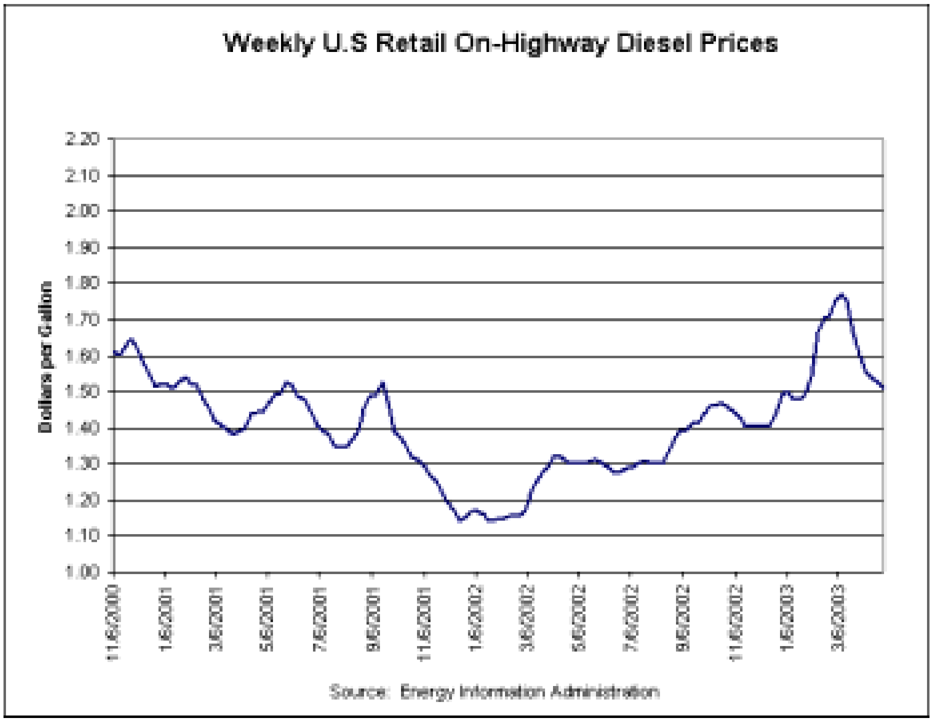
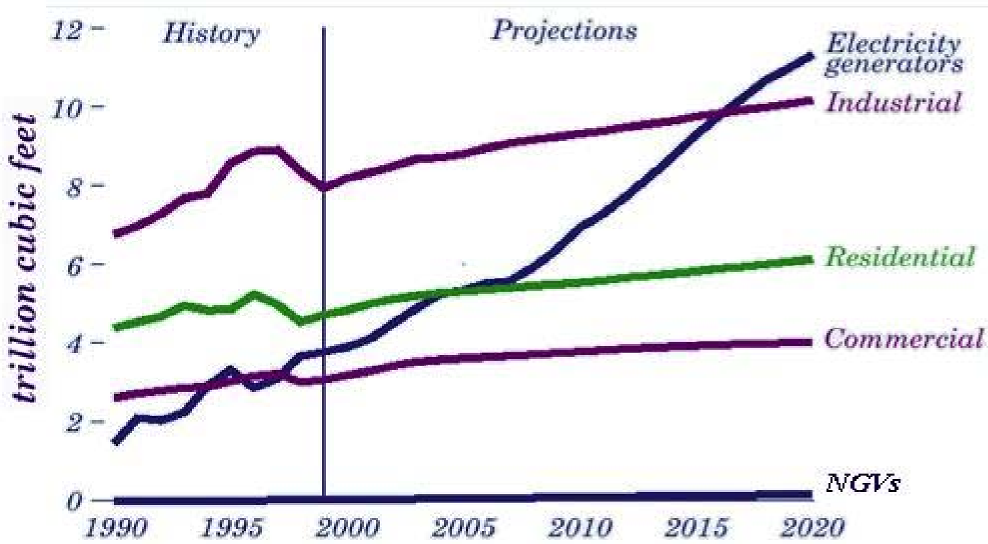


Figure 4-3. Three-year trend in weekly U.S. retail prices for on-highway diesel

Longer-Term Outlook

Nationwide, natural gas consumption is expected to grow by about 60 percent over the next two decades, from 21.4 trillion cubic feet (TCF) in 1999 to 34 TCF in 2020.[101] Rising demand by electricity generators is expected to account for more than 50 percent of the increase, eventually surpassing industrial uses as the largest consumer of natural gas. Demand for natural gas as a vehicle fuel is also expected to grow significantly by 2020, but federal government forecasts indicate that it will remain a fractional percentage of total use in the United States (see Figure 4-4, “NGVs” curve).



Source: U.S. Department of Energy, Energy Information Administration, Annual Energy Outlook 2001, (no significant change in 2003 update).

Figure 4-4. Existing and Projected Growth in NG Consumption for the U.S., by Sector

In California, the Energy Commission has forecasted that the State's demand for natural gas will grow about 2 percent per year from 2002 to 2012 (roughly, from about 6.6 to 8.1 BCF per day). Most of this increase will result from accelerated efforts to build new gas-fired combined cycle electricity generation facilities.[102] This has led to concerns that longer-term supplies of natural gas in California – most of which must be imported via aging pipeline systems – will be insufficient to meet the state's growing demand. This raises concern that high demand and constrained supply will continue to keep natural gas prices high, well above historical trends.

Recent reports from the Energy Commission have further addressed these issues. In 2000, staff concluded "the substantial North American natural gas resources can meet the nation's demand for at least the next 50 years, at current consumption levels." In late 2002 Commission staff predicted that "supplies of natural gas will be sufficient but more costly" than previously forecasted. To accommodate growing demand in California, the report acknowledged that three primary approaches should be used to obtain more natural gas: 1) expand interstate pipeline capacities from other western states and Canada, 2) import more LNG from places like Baja, California, and 3) develop more economical sources of "unconventional" gas. As a result of demand growth and the cost of developing these new sources, the report concluded that "prices for natural gas will likely rise faster than inflation," while staying in the range from $4 to $6 per MMBtu (in constant 2002 dollars, depending on the type of end user) over the next decade.[103]

The federal Energy Information Administration (EIA) has arrived at similar conclusions about the abundance of natural gas and its long-term pricing scenarios. EIA reports have indicated that technological improvements will help increase production and restore reserve levels to historical highs, although periodic price volatility will likely occur. EIA expects the average price of natural gas to gradually increase over the next several years.[104]

Implications of Market Turmoil to CNG and LNG Infrastructure Development

In summary, significant turmoil has occurred over the last several years in current natural gas markets, as with the general energy sector. California is taking important steps that suggest longer-term outlooks for supply and price may be favorable. For the purposes of this Clean Fuels Market Assessment, it is reasonable to assume that sufficient supply will be available to meet the relatively small volumes of natural gas needed in the transportation sector over the next two decades. Pricing in the form of CNG or LNG will likely be volatile on occasion, as is likely with gasoline and diesel. This situation is dynamic and subject to change, making it very difficult to predict the ongoing level of risk associated with funding natural gas fueling stations.

Types of Natural Gas Fueling Stations

As previously described, natural gas vehicles (NGVs) are commercially available from numerous major vehicle and engine manufactures. Natural gas is commonly stored onboard vehicles in one of two forms: compressed (CNG) and liquefied (LNG). CNG vehicles have been the dominant type of NGV sold in the United States, with deployments across many types of light-, medium-, and heavy-duty applications. LNG's conducive properties provide inherent advantages for heavy-duty applications, and it has become increasingly prevalent as the natural gas fuel for refuse haulers and Class 8[105] trucks. Increasing sales in California for both CNG and LNG vehicles are partially the result of regulatory actions by CARB and the SCAQMD, which have created emerging pressures for manufacturers and end-users alike to deploy AFVs (see Appendix A). To support the vehicle deployments required under these regulatory programs, state and local government agencies in California have stepped-up activities to cost share the building of new CNG and LNG stations.

Yet another development is the emergence of "L/CNG" stations as viable alternatives to building CNG stations, in cases where the base load demand is for LNG fuel. These specialized stations (see Section 4.1.2) produce CNG by pumping LNG from the bulk tank to high pressure, then vaporizing and dispensing it -- avoiding the high costs associated with gas compression at conventional CNG stations. L/CNG stations can provide an integrated NGV fueling strategy where suitable. As an example, a transit district that seeks to fuel its "anchor fleet" of LNG buses might specify its station to include the L/CNG feature, so that it could also operate a mix of light- and medium-duty support vehicles on CNG.

Today a mix of CNG, LNG and L/CNG stations is beginning to emerge in California as a reliable, potentially sustainable infrastructure. Each of these natural gas station types is discussed further below.

4.1.1 CNG Stations

Number of Stations

As of early 2003, there are approximately 206 CNG stations operating in California (excluding mini-station concepts such as FuelMaker devices). Currently, about 180 of these CNG stations primarily fuel California's estimated population of 16,000 light- and medium-duty NGVs. Approximately 81 of California's CNG stations offer full or partial public access (see Table 18). The remaining stations limit access to the immediate on-site fleet, or perhaps in some cases, select appropriate NGV users by special arrangement.

Table 18.
Current CNG Fueling Infrastructure in California

Region	Total for All Stations	Public Access
N. California (PG&E)	30	22
S. California (SoCal Gas)	145	50
S. California (Long Beach)	4	4
San Diego (SDG&E)	26	4
Southwest Gas	1	1
Totals	**206**	**81**

Source: Michael Eaves (California NGV Coalition) and Dean Saito (SCAQMD), Co-Chairs of California NGV Partnership Infrastructure Working Group, presentation to the California NGV Partnership, February 20, 2003.

Existing and Needed Fuel Throughput

"Throughput" refers to the volume of fuel dispensed over a given period of time at a fueling station. Throughput at each CNG station is essentially a function of 1) how many NGVs are fueled, 2) how frequently they fuel, and 3) the volume of CNG dispensed during each fueling event. Thus, the highest throughput stations are those that serve large numbers of HDVs (which hold the most CNG and have the highest fuel consumption rates) on a daily basis. Currently, this description most consistently fits major transit bus operations with CNG station capacities exceeding 1000 cubic feet per minute. According to input from one Technical Advisory Group (TAG)[106] member, natural gas throughput at a large transit district can exceed 300,000 gasoline gallon equivalents (GGE) per month.[107]

Stations that dispense medium volumes of CNG tend to be anchored by government or quasi-government facilities such as military bases, small transit properties, and educational institutions. The majority of NGVs operated by these entities are typically medium- and heavy-duty types such as school buses, shuttle buses, meter trucks, cargo vans, large pickup trucks, package vans, step vans, flat-bed trucks, and service-body trucks.

Ironically, the lowest-throughput CNG stations today are those that are more optimized for public access and designed to be as user-friendly as possible. These are the public stations that are not usually affiliated with anchor fleets, and tend to be located at normal gasoline stations on busy thoroughfares.

In the post-deregulation era, the CNG business has shifted from gas utilities to private-sector "turnkey" providers. One result is that low-throughput CNG stations are becoming candidates for closing, while new large-throughput stations are being built for heavy-duty fleets. These turnkey CNG providers generally seek "take or pay" fuel contracts in which the customer will guarantee a minimum gas throughput ranging from 150,000 to 260,000 gasoline-gallon equivalents per year (12,500 to 22,000 GGE / month). Such fuel usage typically requires a large "anchor" fleet of NGVs – typically consisting of HDVs, although high-fuel-use LDV and MDV applications (e.g., taxicabs) can also fill this need.

This need to adhere to a sound business model when building new CNG stations is reflected in the charter of the recently formed California Natural Gas Vehicle Partnership. A key goal of the Partnership is to avoid the "build it and they will come" approach to siting natural gas stations. The Partnership's infrastructure plan primarily targets stations that can attract at least one anchor fleet that can ensure large throughput levels. However, the Partnership also recognizes the importance of expanding the number of public-access stations, and encourages this option whenever suitable, [108] for reasons that are further discussed below.

A number of important dynamics are at work regarding these critical issues of CNG station access, size, throughput, and other factors. These dynamics are now shaping the expansion of CNG stations in California, because gas utilities are no longer in the business of building, owning, or maintaining CNG stations (except stations for their own vehicles). Consequently, stations that can't deliver high fuel throughput and attract major anchor fleets are likely to be candidates for closure.

As an example of these dynamics at work, in early 2000 Shell Oil Company reportedly made the decision to discontinue selling CNG at its three stations in San Diego County, unless a third party could be located to purchase the CNG station components. [109] Although all three CNG stations were found to be operational a year later,[110] as of early 2003 only one Shell station continues to sell CNG in San Diego County. Shell has partnered with turnkey provider Clean Energy to operate this station, which is located at San Diego international airport.[111] Currently, Clean Energy provides "24/7" public access and accepts at least two major credit cards at this station. However, it is very likely that at least one anchor fleet serving the airport area is under contract with Clean Energy to purchase a minimum volume of fuel. Otherwise, this station would not fit Clean Energy's stated business model.

While California's turnkey natural gas providers agree on the critical importance of high fuel volumes to make individual stations profitable, various opinions have been received regarding the specific role that government programs should play. Trillium USA, which specializes in CNG stations for the transit bus market, cites government regulations instead of grant funding as the key to the "economic sustainability" that now exists at high-throughput stations. According to Trillium, "the CNG market is approaching the point where it is economically sustainable (from an infrastructure provider's point of view), and in less need of grant funding." Instead, Trillium has noted, future funding should be targeted more towards vehicles, which would "provide the impetus needed to keep the infrastructure growing." "In the near-term, CNG providers should become less reliant on grant money to open stations, as, at some point, the market forces must take over and allow the industry to develop in a less artificial way."[112] Other turnkey providers agree with Trillium that regulations are important, but disagree that the better target for incentive funding is vehicles and not fueling stations.

Current Price of CNG

The price of CNG at the pump to NGV users varies by the type of customer (high- vs. low-volume), the vendor (e.g., a private company versus gas utilities), and other factors. Generally, trends in CNG pricing closely track the cost of natural gas as a commodity. Figure 4-5 shows how prices for CNG at SoCal Gas stations have closely tracked commodity costs[113] over the period of 1997-2000. Both were stable until mid 2000, with the retail price being about $1.00 per gasoline gallon equivalent (GGE, or 1.25 therms of natural gas). However, from May 2000 to December 2000, the price at the pump increased to as high as $1.67 per GGE. Prices in mid 2001 and into 2002 stabilized back down to their more historical range, with a typical price in Southern California being from $1.40 to $1.60 per GGE.

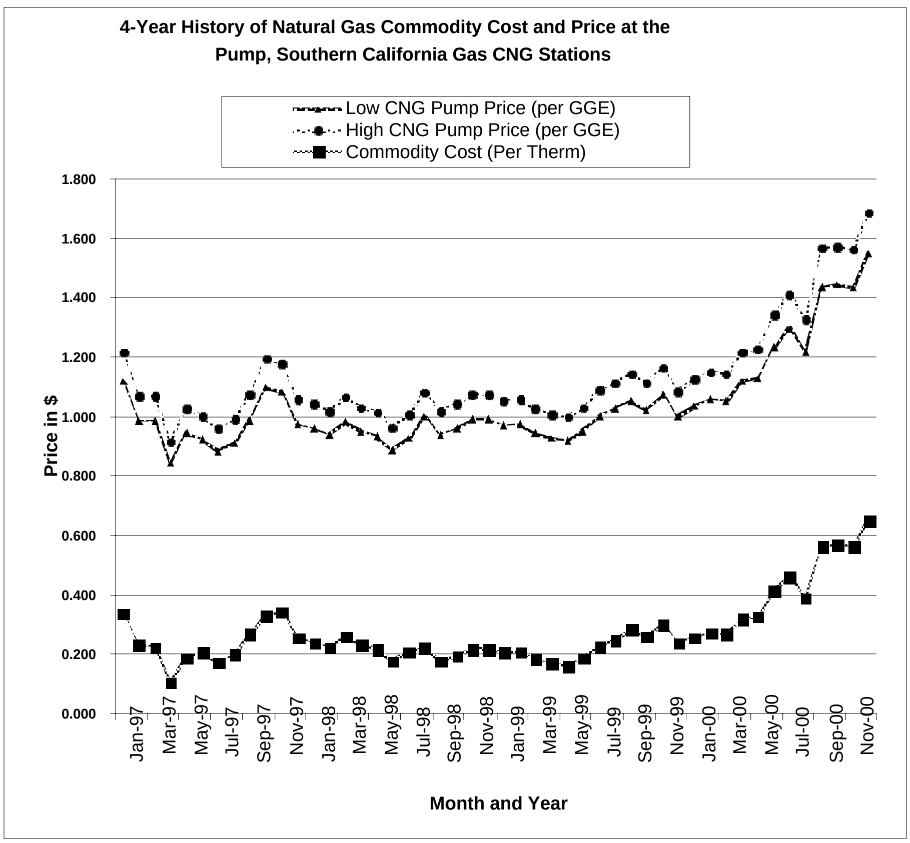


Figure 4-5. The Gas Company's commodity cost and price of CNG, 1997-2000.

As Figure 4-6 exhibits, during the first half of 2003 there was renewed price volatility for CNG, as there was for gasoline (refer back to Figure 4-1 to compare spot prices of natural gas during the same time). The average price at the pump for CNG at SoCalGas's 13 stations has ranged from a low of $1.29 (January 2003) to a high of $1.68 (March 2003).[114] Price trends at other CNG stations throughout California exhibited a similar price trend during this time. To a much greater extent than utility providers, turnkey providers set customer-specific prices for CNG as a function of fuel volume dispensed. The price for CNG that these companies offer their best customers at high-volume stations (at least 200,000 GGE / year) may be well below the price offered at stations that dispense 50,000 GGE / year.[115]

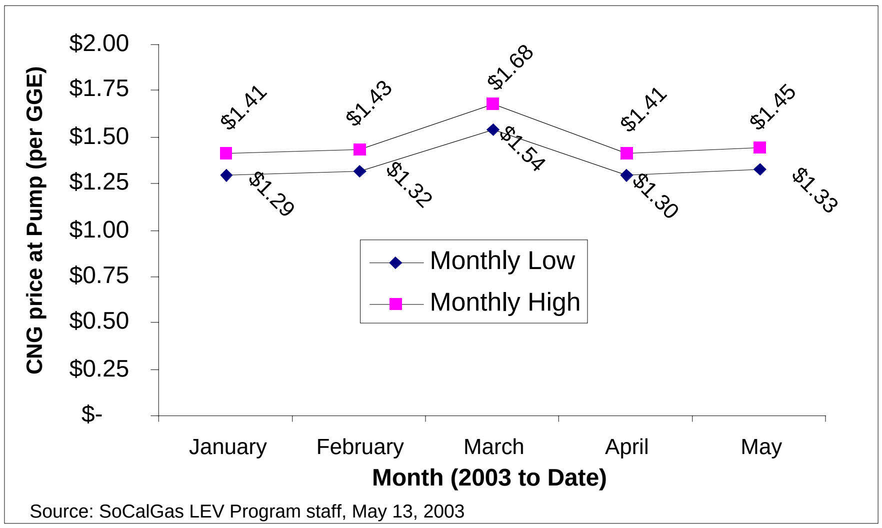
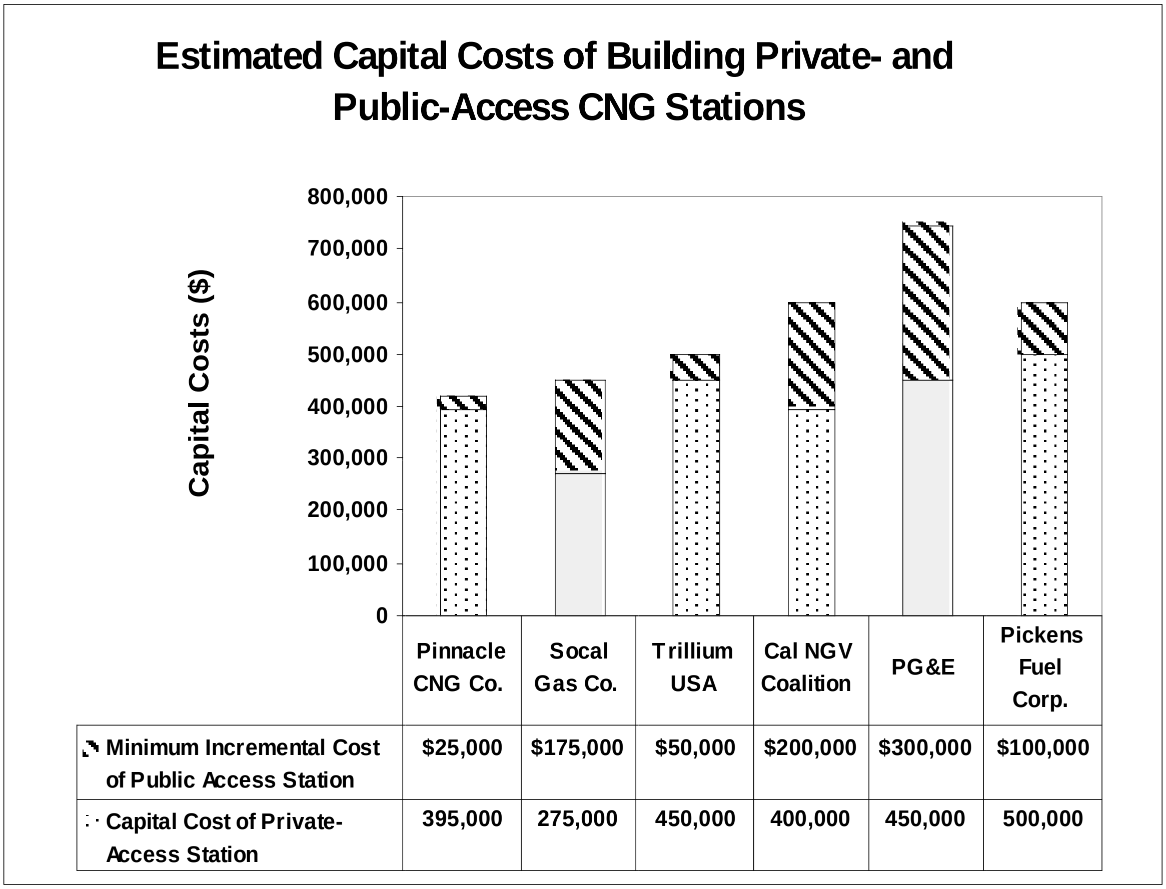


Figure 4-6. Average Prices (2003 to Date) for CNG at SoCalGas Stations

The amortized costs to a major utility such as SoCal Gas for providing CNG to its customers roughly break down as follows: 51 percent for core gas procurement, 27 percent for gas compression, 9 percent for interstate/intrastate transportation, and the remaining 13 percent for various taxes. Gas compression costs refer to the fully amortized costs of building, owning, operating and maintaining CNG fueling stations. The percentage shown relates to the average for a gas utility operating a mix of station sizes. The percentage of total operating costs for a third-party fuel provider at a high-throughput transit station would likely be different.

Station Capital Costs

The current high costs of CNG stations make it difficult for private industry to achieve a reasonable return on investment, unless very high fuel throughput is achieved. Station costs have been a key barrier to wider deployment of CNG stations nationwide. As Figure 4-7 shows, fast-fill systems of mainstream size (300 to 400 scfm) can cost $500,000, and public-access stations are significantly more expensive than private-access versions. According to Trillium USA, the capital costs of CNG stations for large transit bus fleets in California can reach $5 million; one station in New York City cost $7.3 million.



	Pinnacle CNG Co.	Socal Gas Co.	Trillium USA	Cal NGV Coalition	PG&E	Pickens Fuel Corp.
Minimum Incremental Cost of Public Access Station	$25,000	$175,000	$50,000	$200,000	$300,000	$100,000
Capital Cost of Private-Access Station	395,000	275,000	450,000	400,000	450,000	500,000

Source: survey input from TAG members in mid 2001. NOTE: Pickens Fuel Corp. is now Clean Energy.

Figure 4-7. Estimated costs to build CNG stations (approx. 300 to 400 scfm)

For these reasons, private-sector CNG providers primarily seek contracts with fleets that can consume very high volumes of fuel over a guaranteed period of multiple years (see below). Funding from government grant programs has often been provided to help defray station costs – especially those stations that are not affiliated with a large, high-throughput anchor fleet of NGVs. Figure 4-8 shows the range of total costs for CNG stations that the Energy Commission has recently supported.[116] On average, the Energy Commission funded 22 percent of the total cost for these CNG stations. According to a recent estimate from the California Natural Gas Vehicle Partnership, since 1998 more than $31 million of public funds have been invested to cost share some 109 natural gas infrastructure projects in California.[117]

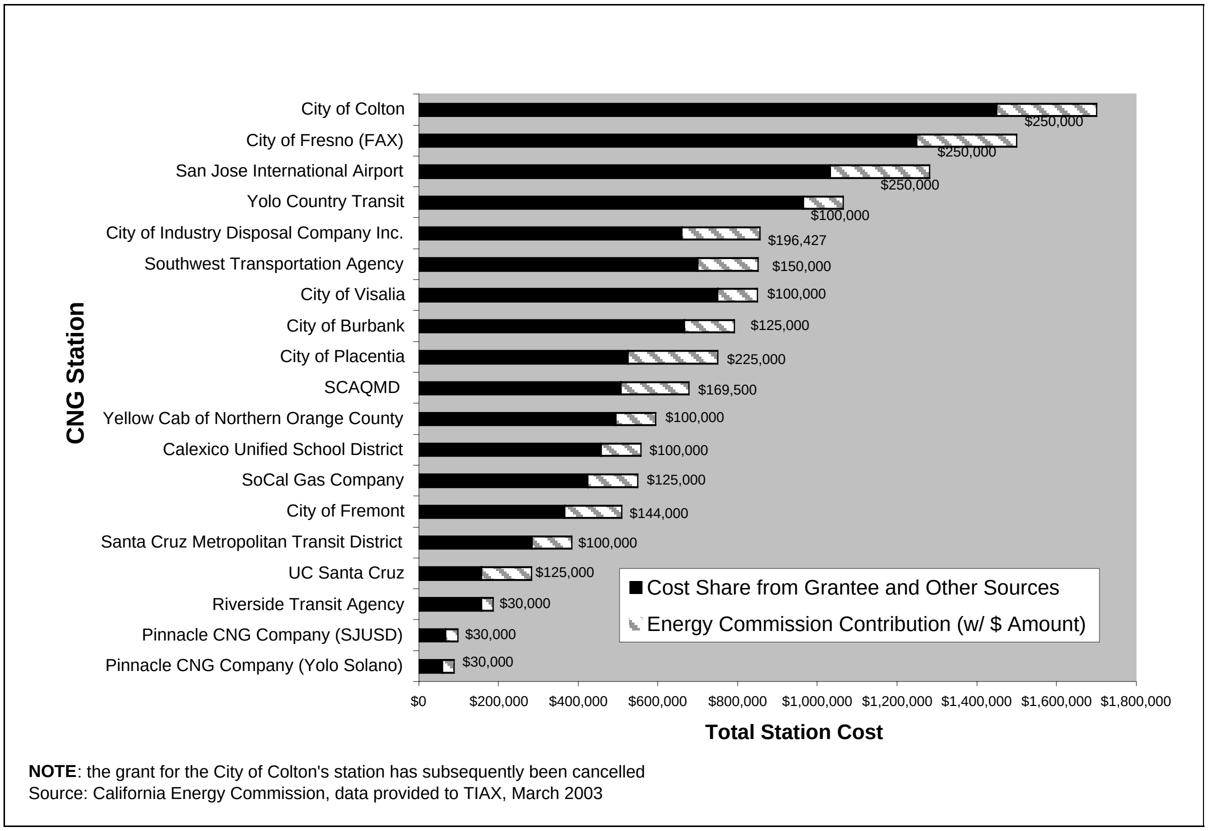


Figure 4-8. CNG Stations Recently Supported by Energy Commission

Station Operation, Maintenance and Training Costs

High operation and maintenance costs (including personnel training) are also major contributors to the relatively high life-cycle costs for CNG stations. Operational costs can be especially hard on user fleets because they are often higher than expected, and the fleets can have insufficient budgets to cover these expenses. Virtually all CNG station components require preventative maintenance on a regular basis to maintain station reliability. The station operator must either pay on-site staff to perform the maintenance, or pay for a contractor's services. Either case can be very expensive.

As a result, today's "turnkey" CNG providers essentially sell natural gas compression services to their customers. These fuel providers are willing to manage all aspects of a CNG facility's installation, operation, and maintenance, in exchange for an agreement by the customer to purchase a minimum throughput of fuel for a set period of time. Increasingly, fleets with very large throughputs of CNG fuel are executing agreements with these turnkey companies. For example, the Los Angeles County Metropolitan Transit Authority (LACMTA) has executed 10-year capital lease agreements with Trillium USA, under which Trillium builds, owns and maintains several CNG fueling stations on LACMTA property. For a 200-bus CNG fueling station, it is estimated that this type of contract can offer a 15 percent cost savings over ten years compared to a large transit district purchasing and operating its own CNG stations.[118]

Trillium USA's initial capital lease agreement with LACMTA was the first of its kind. Other similar agreements have been announced over the last several years. For example, Clean

Energy was recently awarded a $30 million, 10-year contract to design, construct, equip and operate two new natural gas stations for Boston Transit. Fueling operations are scheduled to begin in the summer of 2003.[119]

These types of agreements work well in the cases cited and may represent the future for such NGV applications. However, they are available only to fleets buying high volumes of fuel (at a minimum, about 15,000 gasoline gallon equivalents per month). This equates to approximately 25 heavy-duty CNG vehicles being operated about 100 miles per day, 30 days per month.

Public Access: Hours, Fuel Dispensing and Card Reader Accommodations

CNG stations equipped with the most sophisticated card lock systems -- networked card readers -- utilize a variety of payment cards and software. These systems may offer more features than necessary for private stations, but they are generally considered essential for public-access stations. Before fueling at most public-access stations in California today, it is necessary to establish separate CNG accounts with the operator(s). Each site can vary in their hours of access, equipment, payment method, and on-site assistance. The Clean Fuels Market Assessment 2001 reported that it would require up to nine different account cards to access all of the public CNG stations in California.[120] In some cases dual cards have been necessary -- one for access control and the second for verification of payment.

In the past, the lack of consistency and card commonality has been identified as being a significant barrier to wider NGV commercialization. Over the last few years, government and industry representatives have initiated cooperative efforts to improve point-of-sale payment options at alternative fuel stations. For example, in early 2001 the Department of Energy joined with the National Renewable Energy Laboratory, the Energy Commission and the SCAQMD in a renewed effort to further develop a universal card reader access program. The specific objective was to develop a draft set of performance requirements for open-architecture card reader systems for CNG stations *with equivalent reliability and user-friendliness to gasoline systems*. The immediate focus was on natural gas fueling stations (primarily CNG) in California. However, the intention was to ultimately apply the resulting advancements in open-architecture card reader systems across the United States, at stations dispensing other types of alternative transportation fuels.

This project reinforced previous findings that it has primarily been economic barriers, and not technology limitations, that have hindered progress. Fully automated, integrated hardware-software systems are available today for CNG stations, which can provide the most sophisticated point-of-sale options. However, low fuel sales at today's public-access CNG stations have not justified the associated incremental costs.

Although the ultimate solution lies with increased fuel volume at CNG stations, this project has helped to overcome these barriers. New partnerships are being developed to deploy CNG stations that offer progressively more user-friendly point-of-sale payment options. Over the last two years, some CNG stations[121] have been opened in California that provide 24/7 use of personal credits cards, and provide state-of-the-art cardreader systems as depicted in Figure 4-9.

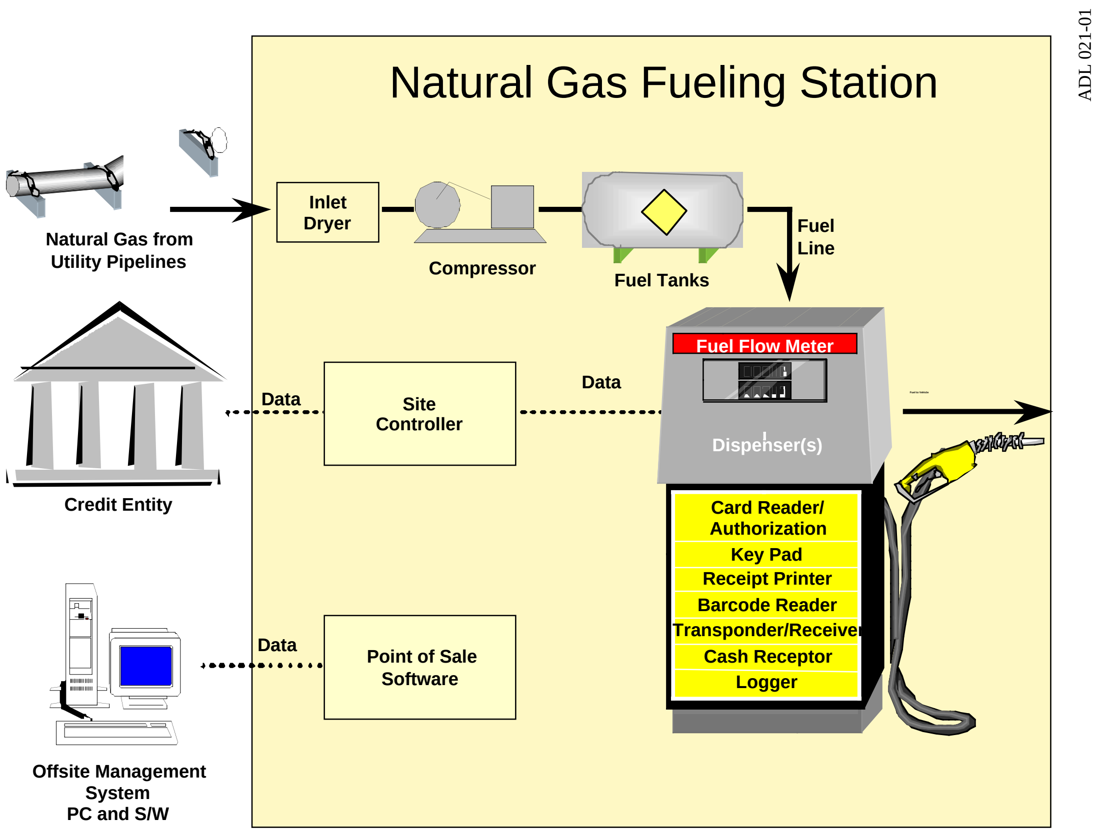


Figure 4-9. Modern, User-Friendly CNG Station with Point of Sale Components

Building Codes and Standards

There are a number of specific codes and standards that must be met when building and/or operating natural gas stations. Some of these apply only to a specific type of station (i.e., CNG or LNG), while others apply to both types. Table 19 below summarizes examples of key codes and standards.

Table 19.
Key codes and standards applicable to natural gas fueling stations

Code / Standard / Requirement	Purpose / Applicability
American Society of Mechanical Engineers, Section VIII Division 1: Design and Fabrication of Pressure Vessels	Structural integrity of pressure vessels.
National Institute of Standards and Technology, Handbook 44: Specifications, Tolerances, And Other Technical Requirements for Weighing and Measuring Devices	Weights and measures for fuel dispensing.
NFPA 52 – Compressed Natural Gas Vehicular Fuel Systems Code – 1998	CNG vehicles and fueling facilities
NFPA 57 – Liquefied Natural Gas Vehicular Fuel System Code – 1999	LNG and L/CNG vehicles and fueling facilities
NFPA 88B – Standard for Repair Garages – 1997	Specific requirements for garages working with NGVs, such as ventilation, electrical requirements near the ceiling, temperature of exposed surfaces on heaters.
NFPA 88A – Standard for Parking Structures – 1998	Open, enclosed, basement and underground parking structures
NFPA 30A – Code for Motor Fuel Dispensing Facilities and Repair Garages – 2000	Facilities dispensing both gaseous and liquid fuels at the same facility
NFPA 59A – Standard for the Production, Storage, and Handling of Liquefied Natural Gas – 1996	Site selection, design, construction, and fire protection for LNG facilities
Uniform Fire Code – 1997	Widely adopted model building code for all of the U.S.
International Fire Code – 2000	A relatively new fire code
ANSI NGV1-1994 (with 1997 and 1998 addenda) – Compressed Natural Gas Vehicle Fueling Connection Devices CNG	Vehicular fueling connection devices
ANSI NGV2-2000 – Basic Requirements for Compressed Natural Gas Vehicle Fuel Containers	CNG fuel containers
ANSI NGV4.1/ CSA 12.5 -1999 – NGV Dispensing Systems	CNG vehicular fuel dispensing systems
ANSI NGV4.2/CSA 12.52 -1999 – Hoses for NGVs and Dispensing Systems	CNG dispenser and vehicular hose assemblies
ANSI NGV4.4/CSA 12.54 -1999 – Breakaway Devices for Natural Gas Dispensing Hoses and Systems	CNG dispenser shear valves and fueling hose emergency breakaway shutoff devices
ANSI NGV4.6/CSA 12.56 -1999 – Manually Operated Valves for Natural Gas Dispensing Systems	Manually operated CNG valves, excluding cylinder shut-off valves
ANSI NGV4.8/CSA 12.8 -2002 – Natural Gas Vehicle Fueling Station Reciprocating Compressor Guidelines	Compressor packages containing reciprocating compressors used in CNG fueling station service
ANSI PRD1-1998 (with 1999 addendum)	Basic Requirements for Pressure Relief Devices for Natural Gas Vehicle Fuel Containers Pressure Relief Devices for CNG Fuel Containers
California Division of Occupational Safety and Health (DOSH) Title 8	Occupational safety at fueling stations
Sources: input from various TAG members, and NexGen Fueling website (http://www.nexgenfueling.com/t_codes.html)	

Time Horizon for Full Technological Maturity

In addition to natural gas supply and price issues, expansion of the CNG infrastructure will depend on growth in deployment of high-fuel-use vehicle sectors. Private companies in the business of supplying CNG (and/or LNG) have established clear business models for building and operating stations. The foundation is at least one anchor fleet per station that is willing and able to purchase major fuel volumes – on the order of 20,000 GGE per month and higher – over a long-term commitment. In the heavy-duty sector, where the largest volumes of fuel are consumed, CNG continues to do well as a fuel for transit bus applications, as evidenced by some of the major “take or pay” contracts that have been announced in recent years. It is notable, however, that CNG is facing a strong challenge from LNG as an alternative to diesel for transit buses. With LNG becoming an increasingly prominent fuel in other HDV applications (e.g., refuse haulers and Class 8 delivery trucks), commercial choices for LNG (engines, chassis and fuel vendors) are expanding. This also expands the choices for transit agencies that are considering deployment of natural gas buses.

CNG from conventional gas-compression stations remains the dominant fuel for light- and medium-duty NGVs. The L/CNG option is emerging as an attractive alternative way to obtain natural gas in its compressed form. However, the density and dispersion of LNG stations inherently limit the availability of L/CNG. Thus, L/CNG stations are likely to mostly *supplement* the conventional CNG infrastructure in providing compressed gas to light- and medium-duty NGVs. Even though market dynamics and competition are at work, this potential synergism between CNG and LNG stations can actually help to improve the long-term viability of NGVs in California.

Regulatory drivers are currently minimal for using NGVs and other types of AFVs in the LDV and MDV sectors. First, conventionally fueled vehicles already meet the most-stringent emission standards for combustion vehicles. Second, current energy-related regulations such as EPACT lack requirements that are effective in stimulating alternative fuel use. However, it’s possible that EPACT amendments will require affected fleets with dual- and flex-fuel vehicles to actually use alternative fuel in their AFVs.[122] This will help secure a sustainable future for CNG-fueled vehicles, as well as other AFV types.

> Notwithstanding these challenges, proponents and suppliers of CNG are optimistic that sustainable growth is underway in California. This has been reflected in the comments and recommendations of TAG members, which were reported in detail in the Clean Fuel Market Assessment 2001. In early 2003, TAG members (including the major “turnkey” providers of CNG) were given the opportunity to provide updates. The most detailed input provided was from the California Natural Gas Vehicle Coalition (CNGVC).

Table 20 provides a summary of specific input from CNGVC executives about station expansion requirements.

Table 20.
Estimated Infrastructure Needs to Meet California's NGV Populations by 2013

Parameter Projected	Light-Duty NGVs	Heavy-Duty NGVs
Estimated total NGVs in California today	16,000	4,000
Projected number of NGVs in California by 2013	500,000	100,000
Average annual increase needed to achieve projection	41%	38%
Projected annual displacement of petroleum fuels	350 million gal. of gasoline	500 million gal. of diesel
Minimum number of stations required to service vehicle population	500 to 600 CNG stations	100 to 200 LNG stations 100 to 200 CNG stations
Source: Michael Eaves, California NGV Coalition, presentation to the California NGV Partnership, February 20, 2003.		

As shown in the table above, CNGVC executives have projected that aggressive growth in NGVs over the next decade will require between 600 and 800 CNG stations serving California's light- and heavy-duty NGV populations. Today, there are approximately 200 CNG stations in California. The CNGVC acknowledges that this type of aggressive growth will require lower-cost stations achieved through a variety of advancements (e.g., standardization and modularization of stations).

CNGVC executives envision that there can be continuity for the CNG infrastructure, serving as a stepping-stone to tomorrow's infrastructure for fuel cell vehicles. They believe that continued growth for the CNG business can be sustained for the next 15-20 years, after which the CNG infrastructure can be converted over for compression of hydrogen reformed -on site from natural gas.[123] The SCAQMD and Sunline Transit Agency are among the organizations in Calfornia that are helping to facilitate and expedite this transition. For example, Sunline Transit Agency produces both CNG and compressed hydrogen at its Thousand Palms headquarters, and operates two special transit buses on a blend of these two fuels.[124] Between its fleet of CNG buses, these two special CNG-hydrogen buses, and a hydrogen-fueled fuel cell bus, Sunline Transit Agency's bus fleet is now 100 percent alternatively fueled, and has collectively logged more than 25 million miles without using any diesel fuel. Sunline's management strongly views natural gas "as the pathway to hydrogen," and believes that providing fleets and AFV users with multiple clean fuel options (as done at its Thousand Palms station) is one key to making a smooth transition.[125]

Advanced Infrastructure RD&D for CNG

Several major programs are underway to improve the commercial viability of CNG fueling stations (Table 21). These programs, which involve a wide variety of public and private entities, all are basically designed to address one or more of the following: 1) reduce lifecycle costs; and 2) improve performance, efficiency, customer access, safety and ease of use. The focus ranges from very large, expensive fueling stations for HDV fleets, to inexpensive time-fill units intended to fuel single vehicles. In this latter category, an informal consortium of government agencies (DOE, the National Renewable Energy Laboratory, the SCAQMD and the Energy Commission) is working with FuelMaker Corporation and American Honda to perform a series of safety and market evaluations on FuelMaker's "home refueling appliance." (HRA). FuelMaker has announced its intention to commercially launch its HRA (named "Phill") in 2004; the anticipated installed price will be under $2,500. The NGV industry and the various supportive government agencies consider the home CNG refueling option to be an important part of the plan to achieve an integrated and sustainable NGV fueling infrastructure.[126]

Table 21.
Major RD&D efforts to improve the CNG infrastructure

Name of CNG Infrastructure Program	Participants	Major Program Objective(s) and /or Projects	Time-frame
Next-Generation Natural Gas Vehicle[focuses on vehicle and engine technology]	Govt.-industry consortium headed by DOE-NREL, with 33 other agencies / companies / organizations	♦ Support next-generation NGVs by enhancing CNG fueling and maintenance infrastructures	Ongoing through at least 2004
California Natural Gas Vehicle Partnership	Public-private partnership initiated by the former SCAQMD Chairman	♦ ID existing and planned infrastructure ♦ Address fuel supply gaps ♦ Address station reliability, redundancy, access issues ♦ Mass deployment of home fueling appliance(s) ♦ Develop infrastructure expansion plan	Ongoing 2002 to 2012
Safety and Market Assessment for Home Refueling Appliance (HRA)	Public-private consortium to commercialize FuelMaker HRA by 2004	♦ Failure Modes & Effects Analysis ♦ Market and user surveys ♦ Garage ventilation study ♦ Other activities	Ongoing from 2002

In addition to these programs, a number of activities are underway to build and deploy state-of-the-art CNG fueling facilities. For example, the SCAQMD has approved "creative settlements" with the Los Angeles Department of Water and Power and AES Alamitos, LLC, for violations of rules and permit conditions. Included in the settlements is a requirement that each entity provide $6.0 million towards expansion of public-access natural gas fueling stations in Southern California. SCAQMD is also funding multiple upgrades to publicly accessible natural gas fueling stations for use by taxicabs and other types of NGV fleets.[127]

Summary of Major Barriers and Impediments

Removing barriers to the CNG fueling network is a high priority for NGV proponents. Vehicle expansion will depend on a significant increase in the number of fueling stations, in parallel with a major increase in vehicle demand. Both private fleet and public access stations are needed, but neither type is likely to be successful unless the private sector can achieve a sufficient return on investment by selling high fuel volumes. Specific threats and barriers to expansion of the network for conventional CNG stations include the following:

- Competition from conventionally fueled vehicles for low emissions, especially in LDVs and MDVs,
- Lack of effective fuel-use requirements in existing energy-related regulatory drivers,
- Ongoing perturbations in California's energy outlook, and competing demand for natural gas to fuel new power plants, in particular,
- High capital, operation and maintenance costs for CNG stations,
- Lack of market demand to justify costs associated with a more open architecture for CNG station card readers, and
- Competition from LNG to capture greater market share in heavy-duty applications (see Section 4.1.2).

4.1.2 LNG Fuel and Stations

Natural gas liquefies at very low temperatures (-258^{o} Fahrenheit at ambient pressure). Advantages of LNG include the fact that it is relatively free of impurities (98 percent methane is a typical specification or goal) and has an energy storage density about 3.5 times that of CNG. Although the energy density of LNG is nearly as high as conventional fuels (gasoline and diesel), it must be stored at very low temperatures, while controlling its high volatility to minimize boiloff (evaporation). This requires properly designed cryogenic equipment consisting of double-walled, stainless steel "superinsulated" vacuum tanks that limit energy transfer (heat) from outside the tank to the cold liquid inside. Because on-board storage of LNG is most conducive to larger vehicles, LNG is used primarily in HDV applications such as transit buses, refuse trucks, and Class 8 trucks. This is because:

1. Many HDVs need more range than can be supplied by CNG within payload space and weight requirements.

2. LNG storage systems cost less than CNG storage systems per amount of energy stored.

3. LNG would evaporate from vehicles that are out of service for more than a week at a time. This is not compatible with private LDVs that may often be parked for more than a week and if indoors, the vaporized LNG could constitute a fire hazard.

As it is drawn from the onboard fuel tanks, LNG is vaporized from the engine's heat. Thus, the fuel that enters the engine is a gaseous mixture as in CNG vehicles, but of higher purity methane.

Number of Stations

As discussed in 3.1.1, by 2007 an estimated 4,000 vehicles may need to obtain fuel from LNG stations in California (LNG for HDVs, or L/CNG for MDVs and LDVs). A preliminary estimate from an Energy Commission Consultant Report is that these vehicles will require 200,000 gallons per day of LNG,[128] or about 73 million LNG gallons annually. As Figure 4-10 shows, meeting this fuel demand will require transport of new LNG supplies into California and/or increased in-state production. The goals of the California NGV Partnership are significantly more aggressive than these projections; they envision about 7,000 LNG vehicles by 2007, with proportionate increases in LNG production supply.

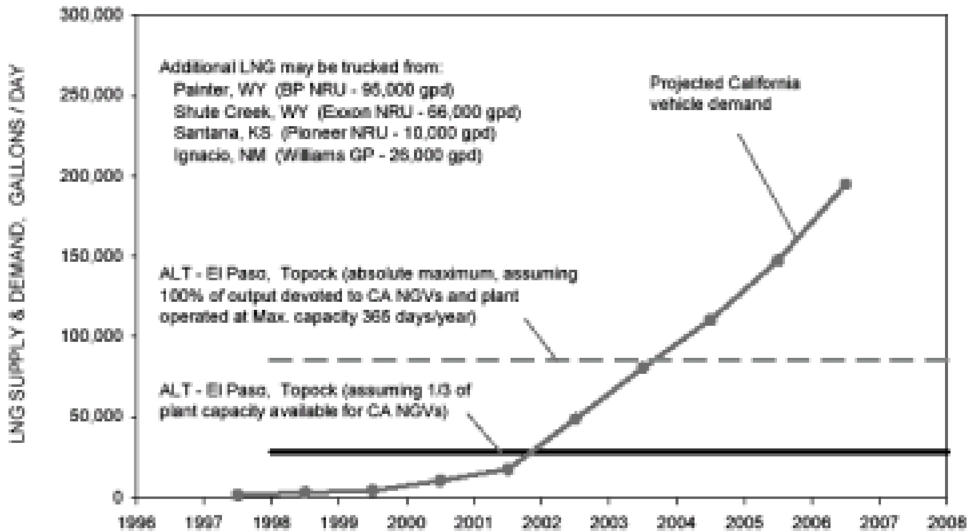


Figure 4-10. Estimated LNG Fuel Demand / Supply for California Vehicles (see Endnote 128)

In conjunction with these fuel supply expansions, adequate numbers of LNG stations must be built to keep pace with vehicle deployments. Over the last two few years, steady progress has been made in the western United States to build new LNG stations. As of early 2003, more than 25 LNG stations are currently operational in California or under construction (see Table 22). Funding from the Energy Commission's Alternative Fuels Infrastructure Program and other government programs have been instrumental in these station deployments. Most recently, the Energy Commission has provided approximately $2.1 million to cost share nine new LNG stations throughout California – these will become operational in the 2004 timeframe (see Figure 4-11). Most LNG stations being installed today include the L/CNG feature, which is further discussed in the next section.

Table 22.
Existing LNG and L/CNG stations in California

Station Operator / Name	Location
1. City of Bakersfield	Bakersfield
2. City of Barstow	Barstow
3. City of Carson	Carson
4. City of Long Beach	Long Beach
5. City of Sacramento*	Sacramento
6. City of San Diego	San Diego
7. City of Tulare*	Tulare
8. County of Sacramento*	North Highlands
9. FleetStar / UPS*	Ontario

10. GTI Rubbish	Simi Valley
11. Harris Ranch	Coalinga
12. L.A. Int'l Airport	Los Angeles
13. Norcal Waste Systems	San Franscisco
14. OmniTrans	San Bernardino
15. OmniTrans	Montclair
16. Orange County Transit Authority	Garden Grove
17. Raley's Supermarkets	Sacramento
18. Riverside County Waste Management	Riverside
19. Sysco Food Services	Walnut
20. Taormina Industries	Anaheim
21. The Vons Companies	Santa Fe Springs
22. USA Waste (Waste Management)	Fresno
23. Vons Groceries	Santa Fe Springs
24. Waste Management	Baldwin Park
25. Waste Management	Palmdale
26. Waste Management	El Cajon
27. Waste Management	Corona
28. Waste Management / SunLine Transit	Thousand Palms
*= L/CNG	

Existing and Needed Fuel Throughput

Currently, LNG is used almost exclusively in HDV applications where large numbers of vehicles fuel on a daily basis (e.g., transit, refuse haulers, and Class 8 trucks). As a result, the existing LNG stations in California all tend to have high fuel throughput, with the largest stations dispensing hundreds of thousands of LNG gallons per month. At these volumes, LNG stations are essentially already commercially sustainable business ventures, although government grant funding has played an important role in enticing private-sector investments, in most cases.

Current Price of LNG

As with other types of alternative fuels, the economics of using LNG as a heavy-duty fuel largely depend on the relative prices of LNG and the fuel it displaces (diesel). LNG is taxed less than diesel fuel but more than CNG, although government fleets get special exemptions.[129] Under current arrangements, transactions for LNG as a transportation fuel are usually private matters between buyers and sellers. Depending on fuel volumes and other factors, prices can be fixed under commercial contracts for periods of months or even years. The net result is that the price of LNG can be higher or lower than diesel fuel (on an energy-equivalent basis), depending on many factors that include feedstock costs, liquefaction technology, transportation distances / logistics, and commercial conditions.

As described earlier, significant price volatility has occurred for virtually all transportation fuels in recent years (for diesel prices, refer back to Figure 4-3 on page 48). While the price of LNG has generally been stable, significant volatility and increases have occurred since mid 2000. At that time, the average price per LNG gallon in California was approximately \$0.50 without tax.[130] Fleets such as Orange County Transit Authority (OCTA) had negotiated long-term contracts for LNG as low as $0.38 per gallon before tax.[131] However, since that time some pricing structures have been renegotiated to account for changing market conditions, [132] and OCTA is now paying $0.53 per gallon.[133] As of mid 2003, the average pre-tax price that LNG fleets are paying in California is approximately $0.65 per LNG gallon.[134] The per-gallon tax paid varies by fleet, with some fleets paying no taxes at all.

To estimate fuel costs relative to diesel for a large HDV fleet using LNG, the energy contents of the two fuels must be taken into account. On an energy basis, $0.65 per LNG gallon is equivalent to diesel fuel at about $1.10 per gallon (both before taxes). For dedicated LNG vehicles, the higher brake-specific fuel consumption (about 20 percent) currently exhibited by most dedicated spark-ignited heavy-duty natural gas engines must also be taken into account. In the end, the fuel cost (or savings) for an LNG fleet comes down to these factors and the price of LNG that can be obtained, which is very much driven by the volume purchased and the willingness of both buyer and seller to commit to long-term contracts.

Station Capital Costs

According to input from TAG members involved with LNG infrastructure development, the capital cost of building an LNG station (~15,000 gallon capacity) ranges from $650,000 to $800,000 (excluding land costs). These estimates are consistent with information provided by Chart Applied Technologies, a major vendor of LNG fueling stations. Chart's prices (including setup, installation and operational training) range from about $50,000 for a single-hose "demonstration fueler," to about $1.37 million for a top-of-the-line LNG station with four dispensers (see Table 23).

Table 23.
Ranges of LNG Station Prices from Chart Applied Technologies

Station Type (Designation)	# of Dispensers	Storage (LNG gal)	Fleet Size (# of HDVs)	Station Price Range (with Installation)
Lowest Cost Integrated Skid, no fuel metering (Skidded 6000)	1	6,000	27-60	~$250,000 to $500,000
Modular Station, Weights and Measures Dispenser (Mod.15+/1)	1	15,000+	27-60	~$600,000 to $650,000
Modular Station, W&M Dispensers, capability for adding more storage (Mod.15+/2)	2	15,000+	27-80	~$600,000 to $700,000
Modular Station, W&M Dispensers, capability for adding more storage (30+/3)	3	30,000+ (2X15,000)	75-135	~$1,100,000 to $1,200,000
Standard Station, W&M Dispensers (45/4)	4	45,000 (3X15,000)	135-210	~$1,250,000 to $1,375,000

Source: adapted from materials provided by Chart Applied Technologies, LNG Vehicle systems Training Seminar, February 2001.

When taking into account land costs, site and building upgrades, and all necessary hardware additions and modifications, large LNG stations such as those needed to fuel hundreds of heavy-duty vehicles can cost several million dollars.[135] Figure 4-11 shows the total reported costs for nine LNG stations being built with the assistance of cost sharing from the Energy Commission (note: some stations include the L/CNG feature – see Section 4.1.3.). Most of these stations fall within a range of $1 to $3 million.

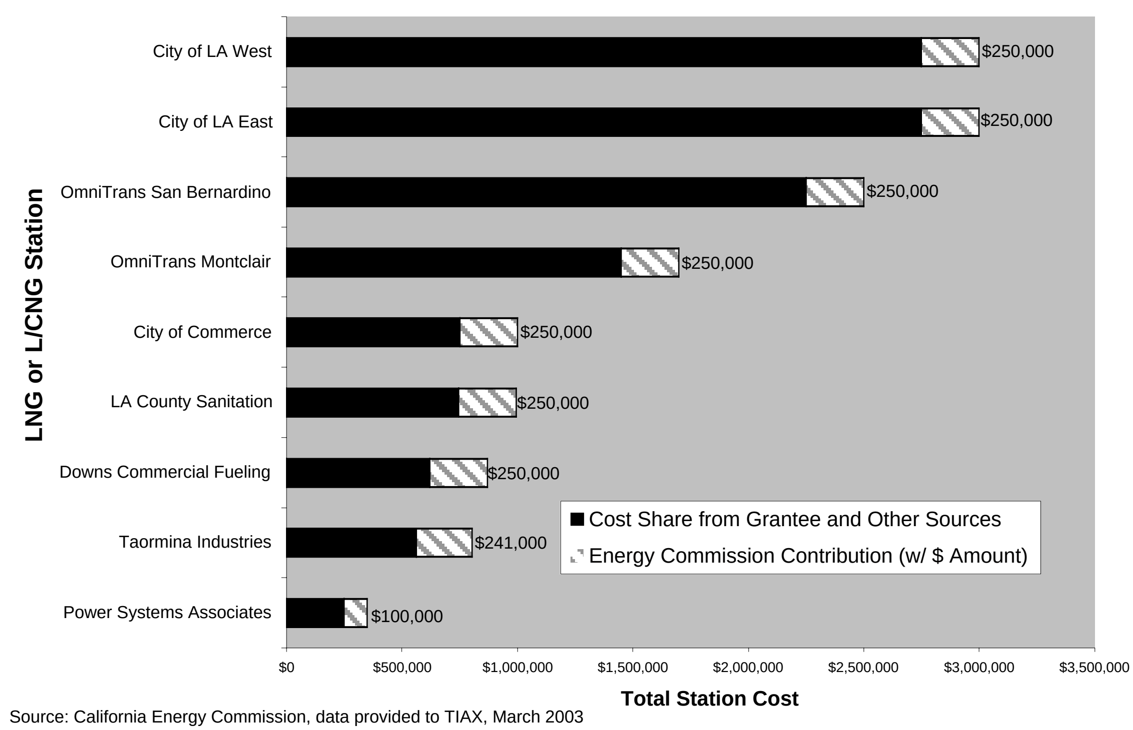


Figure 4-11. Costs for New LNG and L/CNG Stations Partly Funded by CEC

Station Operation, Maintenance and Training

On a fuel throughput basis, LNG stations have lower O&M costs than CNG stations. The main reason is that LNG stations do not need gas compression and drying systems. Still, LNG stations require significant scheduled maintenance activities. Similar to the situation with CNG, turnkey LNG providers are emerging that are willing to manage all aspects of an LNG facility installation, operation, and maintenance, in exchange for an agreement by the customer to purchase a minimum throughput of fuel for a set period of time. Clean Energy (formerly ENRG and Pickens Fuel Corporation) is one such operation that offers "take or pay" agreements to fleets with very large throughputs of LNG. Estimates on the fully burdened maintenance costs for an LNG station dispensing about 30,000 LNG gallons per month range from $0.03 to $0.06 per LNG gallon. This amounts to an annual maintenance cost ranging from $12,000 to $22,000 for an LNG station of this size.[136,137]

Typically, station vendors include training (vehicle refueling and safety) for end users as part of station start-up costs. However, this may be limited to one or two days with no provision for follow-up training. LNG fleets are typically large enough to afford and justify their own ongoing training programs.

Public Access: Hours and Accommodations

LNG stations are primarily used to fuel large heavy-duty anchor fleets. Users of light- or medium-duty NGVs, including the general motoring public and fleets, do not need access to LNG stations. However, CNG vehicles can be fueled at LNG stations that include the L/CNG feature. Thus, some L/CNG stations include a private-access LNG side as the main fueling station, while offering a publicly accessible side that dispenses CNG on a 24-hour basis with point-of-sale options similar to comparable CNG stations. The inclusion of this type of set up is probably why some LNG stations in California are listed on fueling station websites as offering public access.

Building Codes and Standards

LNG stations must meet similar standards and codes as CNG stations (see Section 4.1.1). The main requirements are NFPA 57 (Liquefied Natural Gas Vehicular Fuel Systems Code, 1999 Edition) and NFPA 59A (Standard for the Production, Storage, and Handling of Liquefied Natural Gas, 1996 Edition).

Time Horizon for Sustainable Economic Viability

The long-term economic viability of LNG in California as an HDV fuel will be closely tied to a variety of complex, intertwined factors. These include the relative prices of LNG and diesel, the numbers of LNG vehicles deployed, the corresponding fueling infrastructure, available fuel supplies, and the existence of tax deductions and incentives for end users. Initially at least, competitive economics will most likely be achievable only in large return-to-base fleets that operate grocery trucks, transit buses and waste haulers.

From the perspective of at least one turnkey provider, the LNG stations it builds for these types of fleets are "stand-alone profit centers" even in this relatively early stage of the NGV market. According to this vendor, profitability is "guaranteed" in the pricing and volume requirements of each station's contract. Thus, a "critical mass" of LNG stations throughout California is not needed – as long as each individual station has high throughput and at least one heavy-duty anchor fleet.[138]

LNG fueling station economics also have to make sense for the fleet operator, of course. A 2001 study sponsored by DOE's Brookhaven Laboratory and the Gas Technology Institute[139] prepared life-cycle cost models for these same three types of LNG fleets (refuse haulers, grocery trucks, and transit buses). The study predicted that larger fleets will obtain significant annual cost savings when using LNG vehicles (either dedicated or pilot-ignited versions) instead of diesel vehicles (usually, for 100% of their HDV fleet). These savings will vary by fleet type and be "highly dependent" on LNG prices remaining lower than diesel on an energy equivalent basis. This requires LNG pricing over time that provides end users with long-term operational savings while also ensuring LNG suppliers with an acceptable return on investment. Other important elements of future success may include 1) continued availability of government incentives to offset the higher capital costs of LNG vehicles and fueling stations, and 2) continued existence of regulatory drivers (e.g., SCAQMD's 1190 Series fleet rules and the state public transit fleet rule) for heavy-duty AFVs.

Over the last five years, a combination of these success elements has helped deploy a significant number of LNG vehicles in California. However, a number of challenges remain for LNG to become a sustainable transportation fuel in California (see next section). The long-term viability depends on many factors that will likely be played out over the next five to 10 years.

LNG-Specific Supply and Demand Issues

LNG is currently imported to the U.S. on both the East and Gulf coasts. As a response to the 2001 energy crisis in California, there were a number of announcements made about potential new commercial ventures to bring more LNG production to California. While progress is being made, most LNG product consumed in California today is still obtained from a single source: the 86,000 gallon-per-day liquefaction plant in Topock, Arizona.[140] This plant, which is owned by El Paso Field Services, produces LNG for three main applications: industrial, municipal (gas utilities), and transportation. Applied LNG Technologies USA owns the LNG fuel storage and trucking operations that facilitate delivery to California markets. Under current allocations, an estimated one-third of the plant's output (i.e., approximately 29,000 gpd) is available for use as a transportation fuel in California's heavy-duty LNG fleets.[141] Additional LNG supplies are 1) trucked in by Clean Energy from plants in Wyoming and the Pacific Northwest, and 2) obtained from a few in-state liquefiers.

Despite new activities to bring additional sources of LNG on line for the California market, concern continues that there will be insufficient LNG fuel to accommodate expected growth in LNG vehicle deployment. In early 2002, USA Pro & Associates and St. Croix Research completed an assessment for the Energy Commission on this important issue. The authors concluded that California LNG transportation fuel demand is likely to begin exceeding existing supply from El Paso's Topock plant in 2002. This will "require significant reallocation of the Topock plant production and/or trucking of LNG from more distance sources" if the growing demand for LNG is to be met. They noted that "LNG plants currently being installed plus those in the planning stage are unlikely to generate enough additional supply to eliminate a supply-demand deficit in the 2002 to 2005 time period." Among the report's conclusions was that California's longer-term supply of LNG for transportation applications will need to be augmented by "more small-scale and/or turboexpander plants (if initial projects are successful), large purpose-built LNG plants (which do not appear to be profitable investments at current economic conditions), and LNG import terminals (which are highly uncertain)."[142] The chances of success were not specifically estimated, but it is clear that LNG supply issues present a formidable challenge to the sustainability of LNG as a transportation fuel in California.

Advanced Infrastructure RD&D

Table 24 provides examples of RD&D efforts and government programs that are underway to help overcome barriers and improve the economics of LNG commercialization.

Table 24.
Major RD&D efforts to improve the L/CNG infrastructure

Name of L/CNG Infrastructure Program	Participants	Major Program Objective(s) and /or Projects	Time-frame
Next-Generation Natural Gas Vehicle	Gov't.-industry consortium headed by DOE-NREL, with 33 other agencies / companies / organizations	• Support next-generation NGVs by enhancing L/CNG fueling and maintenance infrastructures	Ongoing through at least 2004
California Natural Gas Vehicle Partnership	Public-private partnership initiated by SCAQMD Chairman	♦ ID existing and planned infrastructure ♦ Address fuel supply gaps ♦ Address station reliability, redundancy, access issues • Develop infrastructure expansion plan	Ongoing 2002 to 2012

Accelerated deployment of "waste-to-energy" technologies has potential to help increase California's natural gas supply for transportation applications. For example, decomposition of biomass, industrial waste, and municipal solid waste produces large volumes of methane in California, as does anaerobic digestion of organic waste. These processes typically produce gas that is relatively low in methane content (between 40 and 75 percent), and therefore considered low to medium in energy content. Depending on the extent of the cleanup processes, these waste gases can be used to generate power or electricity in reciprocating engines, combustion turbines, steam cycle power plants and microturbines. [143] A report for the Energy Commission found that 38 landfill-gas-fired electric power generation projects are operating in California with an aggregated capacity exceeding 200 MW, and "potential projects could more than double this capacity." [145]

Limited efforts are already underway to develop "small-scale liquefaction" plants that can use remote or renewable gas sources to produce LNG, at or near the end user's fueling station. Pilot projects have been announced to assess the economics and logistics of these gas-to-liquid processes. Perhaps the biggest barrier to this approach is that gas cleanup costs from landfill sources can be significant. For example, the Energy Commission and other agencies planned an effort at San Diego County's South Chollas Landfill to capture, clean up, and liquefy landfill gas instead of flaring it into the atmosphere. The intent was to generate an estimated 3,300 LNG gallons per day by 2005 to fuel the City's fleet of LNG refuse haulers.[148] However, in 2003 the South Chollas Landfill project was cancelled -- problems included inadequate purity of the landfill gas and insufficient volumes to make liquefaction practical.

More immediate efforts are underway in California to develop and demonstrate cost-effective small-scale liquefaction plants using pipeline gas. For example, under a cooperative R&D program that includes the Energy Commission, federal agencies and two California utilities, a 10,000-gallon-per-day liquefier has been installed in Sacramento at a very compact site previously housing a CNG facility. The unit went on line in mid 2002, but as of early 2003 it was still undergoing system optimization and testing.[149] Ultimately, the fuel will be used at an L/CNG station used by the City and County of Sacramento. The cost of the 10 ft. by 12-ft. liquefier is believed to be about $450,000. A full-sized LNG liquefaction plant costs about $10 million and requires several acres of land.

And, as of mid 2003, the SCAQMD has selected projects for four new LNG plants within southern California, which will deliver as much as 135,000 LNG gallons per day within a few years. These projects will involve conventional gas separation technology and not the more experimental process being developed for other projects in the state (e.g., Sacramento's small-scale liquefaction plant).[150]

Despite steady progress in recent years, additional efforts are needed in California to produce LNG and other clean transportation fuels from unconventional feedstock. Potential strategies include further exploiting California's large untapped resources of waste-to-energy technologies, and using emerging gas-to-liquids technology to extract stranded reserves of associated natural gas, which can yield LNG, synthetic diesel fuel, and methanol (among other useful products). Some of these programs are already underway, such as efforts by a least four companies to develop pilot plants to produce synthetically derived Fischer-Tropsch diesel fuels. It is expected that Fischer-Tropsch will grow significantly over the next several years as a "high-end blend stock" for diesel fuel in California.[151]

Summary of Major Barriers and Impediments

There are a number of key barriers and impediments for the LNG infrastructure in California. Many of these are similar to CNG, except that LNG is fully focused on the HDV sector, unlike CNG. The most critical barriers for expanding the LNG infrastructure include:

- Competing growth in demand for natural gas, especially to fuel new power plants,
- Logistics and costs of importing LNG to California by trucks and ships,
- Relatively few engine and vehicle models compared to diesel,
- Longer lead times for procurement of vehicles,
- High cost of fueling stations and vehicle components (e.g., on-board LNG tanks), and
- Lower engine efficiency compared to diesel (associated with the change from compression to spark ignition, as needed to combust most alternative fuels in dedicated engines).

4.1.3 L/CNG Stations

A third type of natural gas fueling facility, known as an "L/CNG" station, is a specialized LNG station that also supplies CNG. Such stations consist of a conventional LNG system, with the addition of high-pressure cryogenic pumps that compress some of the LNG to 4,000–4,500 psi, and then vaporize the highly compressed liquid. CNG derived from this process offers certain advantages over conventional CNG. First, cryogenic pumps require significantly less energy than the compressors used at conventional CNG stations, and are less maintenance intensive. Second, L/CNG is delivered to NGVs at ambient temperature, which helps to achieve complete fills without the need for temperature compensation systems.[152] In addition, since transportation LNG fuel is nearly pure methane (98 percent), L/CNG is delivered to the vehicle with virtually no contaminants or undesirable fuel elements such as oil carryover, moisture, and higher hydrocarbons. This eliminates the need for gas drying and filtering systems.[153] However, the lack of oil in L/CNG can also have negative consequences, since some lubricity is needed for many NGV fuel injector systems (discussed further below).

Adding the L/CNG option when building a new LNG station costs approximately $150,000 to $200,000. Retrofitting an existing LNG station with the L/CNG feature costs approximately $200,000 to $250,000.[154] Despite these additional costs, L/CNG stations have potential to be cost-effective alternatives -- *where significant demand exists for both CNG and LNG fueling.* L/CNG provides an integrated deployment strategy for NGVs. This enables fleets to fuel light- and medium-duty CNG vehicles at the same facility as heavy-duty LNG vehicles. Today, many of the LNG stations being built with public funds in California include the L/CNG feature. Still, it must be emphasized that LNG stations offering the L/CNG feature will only play a supplemental role in providing the volume of CNG needed to sustain California's NGV population. By 2013, the NGV industry projects that there will be five times more CNG vehicles than LNG vehicles on California's roads, although the total consumed quantities of CNG and LNG on an energy basis may be comparable. The large majority of these CNG vehicles will be fueled at conventional CNG stations.

More information is needed to assess the long-term performance, reliability, and life-cycle costs of L/CNG stations. As noted, one key question about L/CNG involves its lack of lubricity for some natural gas vehicle fuel injectors. Since compressed fuel from an L/CNG station has very low lubricity, at least one NGV manufacturer has indicated that injector warranties may be void when using L/CNG. To address this issue, some L/CNG stations inject low levels of lubricant into the methane stream after it is vaporized and compressed at high pressure for delivery to vehicles. This is the opposite problem encountered with conventional CNG, which can have too much "oil carryover" from the natural gas compressor, resulting in damage to the fuel injection system and other parts of the NGV.

4.2 LPG Fuel and Fueling Stations

Propane, the main constituent of Liquefied Petroleum Gases (LPG), is a colorless, odorless, tasteless, and non-toxic hydrocarbon. Propane is a gas in its natural state, but it turns to liquid under moderate pressure. When used in vehicles, propane is stored in special fuel tanks and pressurized to about 200 psi. Similar to how LNG is used on vehicles, when liquid propane is drawn from the tank it is vaporized to a gas before being burned in the engine.

Nationwide, most propane produced today is recovered from natural gas through a separation process called fractionation. However, refining of crude oil accounts for a greater percentage of production in California, due to the high concentration of refineries in the state.

Propane is shipped to retail storage sites through pipelines as well as on railcars, transport trucks, and barges. For safety purposes (similar to the case with CNG), ethyl mercaptan is added to propane as an odorant when it is loaded into transport trucks or onto railcars. Bulk trucks typically make the final delivery in 1,800- to 5,000-gallon cylinder trucks.

Number of Stations

Today there are approximately 1,200 facilities in California that dispense propane. According to the Western Propane Gas Association, more than half of these facilities are capable of providing propane as a motor vehicle fuel. [155] However, only about 3 percent of the total LPG dispensed is used for transportation applications (see Figure 4-12). The vast majority is used for petrochemical applications, and to fuel residential and commercial applications such as heaters, recreational vehicles and barbecues.

Based in part on the recommendations from the Clean Fuels Market Assessment 2001, the Energy Commission recently allocated funding to help build or upgrade 13 propane stations in California for automotive applications. These self-serve stations will be significantly more sophisticated and user friendly compared to those that dispense propane for the portable container market. They will be located on typical fueling islands and equipped with gasoline-style dispensers that meet weights and measures requirements, complete with cardreader systems that can accept typical fuel-purchase cards used by fleets (e.g., Voyager). Each of these 13 stations is being strategically located near fleets that operate bi-fuel pickup trucks, such as Caltrans' various facilities throughout the State.

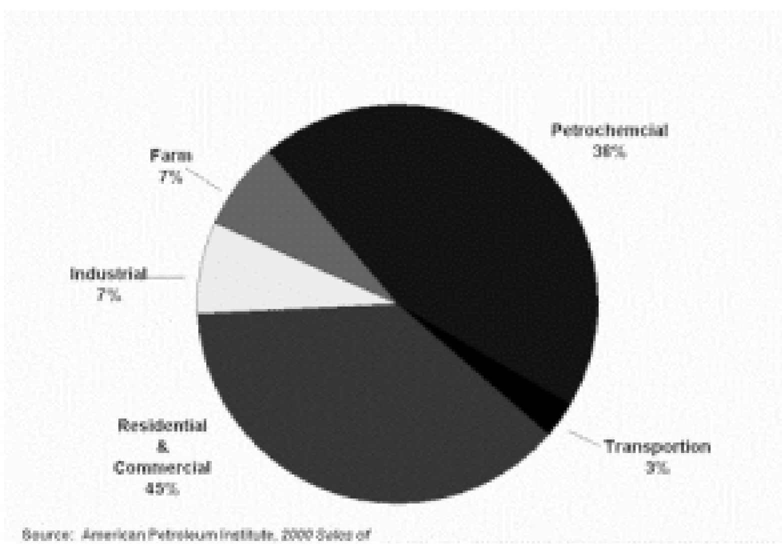


Figure 4-12. Current Propane Demand Sectors in U.S. (from www.EIA.DOE.gov)

Existing and Needed Fuel Throughput

LPG has long been used as a mainstream fuel for barbecues, outdoor heaters, forklifts and recreational vehicles. California's existing LPG stations, which primarily serve these markets, are well-dispersed in key locations. These stations are generally owned and utilized differently than natural gas fueling stations (CNG or LNG). LPG end users often own and operate their own fueling stations, because they are inexpensive to install and have relatively low life-cycle costs.[156] As a result, the LPG infrastructure is commercially self-sustaining today, and government financial support has generally not been necessary.

The network of fueling stations would need to be significantly expanded before propane can become a mainstream transportation fuel. Automotive propane stations offering cardreader-equipped island dispensers and full public access are more expensive to build than those used to fill portable five gallon tanks and recreation vehicles (see Figure 4-16), although they are less expensive than comparable natural gas stations. To the fuel provider, the added cost of building an automotive propane station can be justified by the higher throughput that is likely to result. This in turn results in a lower price at the pump per gallon of propane (see next section and separate report entitled California Alternative Fuels Infrastructure Program Evaluation.

LPG Demand, Supply and Price

Each year approximately 500 million gallons of propane are sold to California's end users, including fuel used to replenish secondary inventories. Retail consumption in California ranges from 375 to 410 million gallons per year, "with weather a large part of the variance."[157] The breakdown of how this propane is used in California by various sectors is similar to that shown for the entire U.S. (Figure 4-12, above).

As Figure 4-13 shows, propane is produced through both natural gas processing and petroleum refining. Texas produces about one third of the nation's supply, and has more than half of the underground storage capacity. In addition to these two processes, demand is met by imports of propane and by using stored inventories. Although imports provide the smallest (about 10 percent) component of U.S. propane supply, they are vital when consumption exceeds available domestic supplies of propane. Propane is imported by land (via pipeline and rail car from Canada) and by sea (in tankers from such countries as Algeria, Saudi Arabia, Venezuela, Norway, and the United Kingdom).

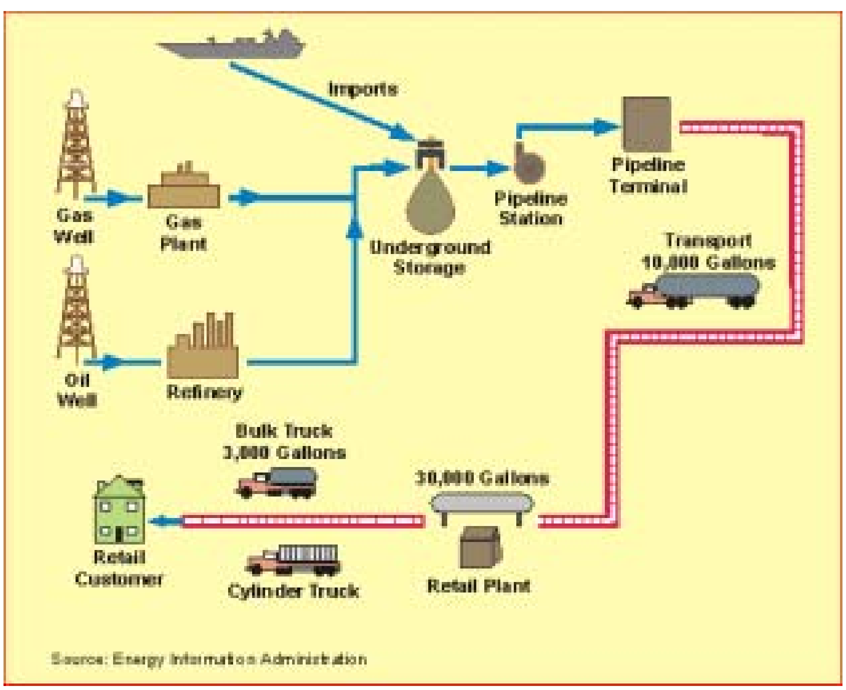


Figure 4-13. Production chain for propane (from http://www.npga.com)

Estimates vary, but it is commonly understood that approximately one-half of California's propane supply is produced as a by-product of natural gas production or other non-petroleum sources, while the remainder comes from petroleum refining.[158] The distinction about feedstock can be important when considering propane's status as a "non-petroleum" alternative fuel that "displaces" gasoline and diesel. Also, feedstock affects fuel quality: refinery production results in LPG that includes propylene (also known as propene), which is an undesirable component for motor fuel due to its high photochemical reactivity (smog-forming potential). Finally, because refinery expansions may be limited in the future, and given that a large portion of California's propane comes from refineries, the question has been raised as to how California would meet a major increase in propane demand (as might occur for automotive applications).

According to the propane industry's perspective, California is not overly dependent on petroleum-derived propane, and significant increases in future demand can be met without increasing foreign imports. The industry recently reported to the Energy Commission that "there are more natural gas liquids and liquefied refined gases produced and/or supplied in California than the market requires now, or in the foreseeable future." The industry did note, however, that "the 'propane' component of those liquids is not always available to the retail market."[159] The implications of this footnote are unclear.

Regardless of this feedstock debate, from a practical standpoint propane has become firmly established in California as a certified, low-emission alternative fuel, and it is an EPACT-certified fuel under the federal definition. In essence, the use of propane as a transportation fuel meets the core objectives of the State's efforts to displace petroleum fuels, as well as those under the Energy Commission's Alternative Fuel Infrastructure Development Program. Most significantly, the use of propane as an automotive fuel is consistent with, and complementary to, the objectives outlined in Assembly Bill 2076 and Senate Bill 1170. Exclusive use of propane in the state's 1,610 bi-fuel vehicles would provide 44% of the reductions needed in gasoline consumption for the state's entire fleet, as targeted by January 2005 under Senate Bill 1170.[160]

On a broader scale, the LPG industry has stated that the U.S. LPG supply is currently sufficient to operate millions of vehicles per year.[161] Worldwide, there is ample LPG supply, but prices drive product distribution. Since U.S. suppliers compete in a global market for LPG, a sudden, heavy demand for LPG due to colder weather usually results in prices escalating rapidly.[162] The National Propane Gas Association has acknowledged this concern with the following statement:

> "It is important to understand that the by-product nature of propane production means that the volume made available from natural gas processing and oil refining cannot be adjusted when prices and/or demand for propane fluctuate."[163]

Propane is traded on the commodities market; consequently, the price of LPG changes daily. LPG prices are subject to a number of influences; some are common to all petroleum products, and others are unique to LPG. Because LPG is essentially the most portable gaseous fuel, it is typically used for home heating in regions where natural gas pipelines don't exist. It can also serve many other different markets, from fueling barbecue grills to producing petrochemicals. The price of LPG in these markets is influenced by many factors, including the prices of its feedstocks (natural gas and crude oil);), prices of competing fuels in each market; , the distance LPG has to travel to reach a customer; , and specific issues within individual markets served (e.g., residential, fork lifts, etc.).

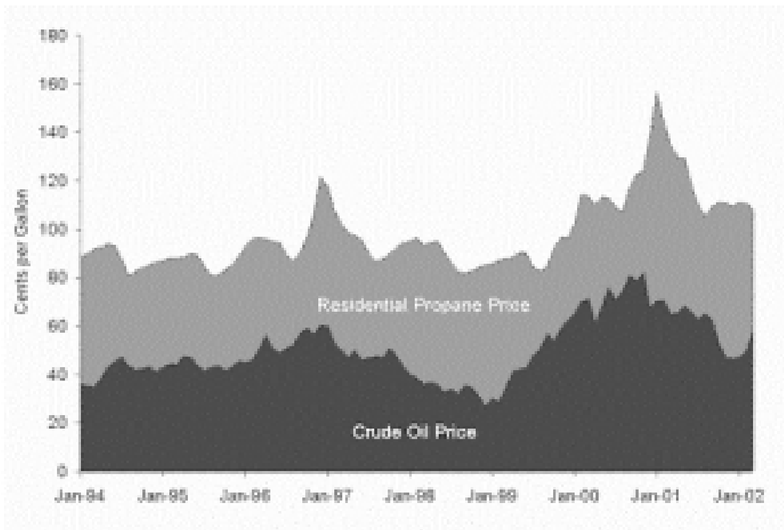
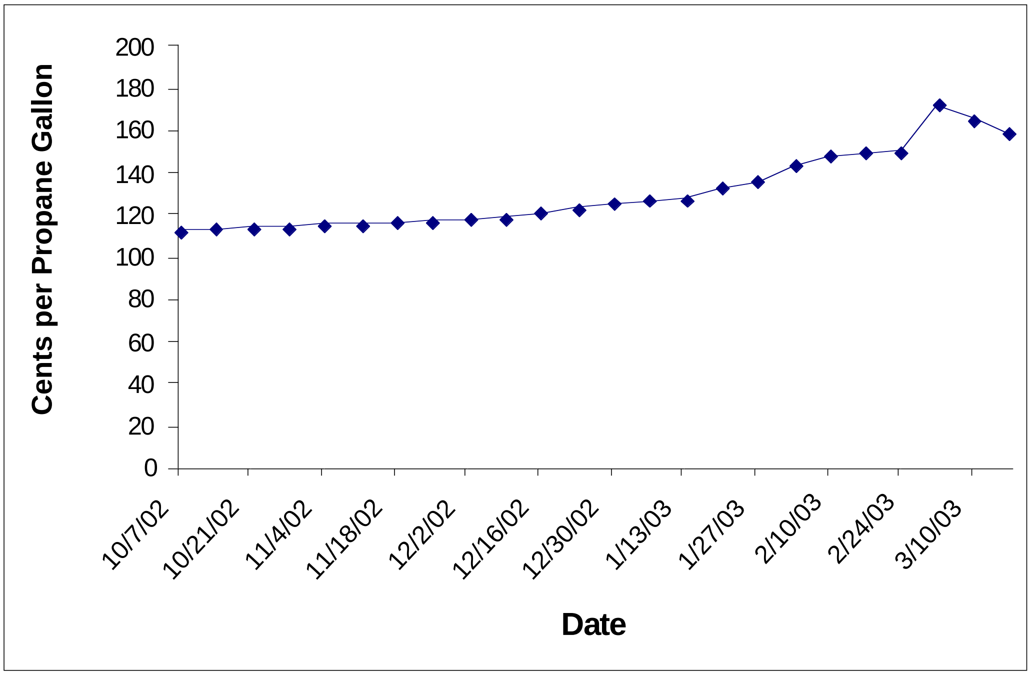


Figure 4-14. Retail LPG prices generally track those of crude oil (source: EIA).

As Figure 4-14 shows, the retail price of propane has closely tracked the wholesale price of crude oil over the last eight years. When high crude oil prices occurred in late 2000 and early 2001, the residential price of propane also exhibited significant increases. According to Purvin & Gertz, Inc., an international energy industry consulting firm, the following factors resulted in increasing LPG prices during the winter of 2000/2001, in addition to crude oil price increases:

- U.S. propane inventory levels were the lowest since 1996, even though stocks were continuing to build,
- Record high natural gas prices occurred,
- Imports of propane to the U.S. were down over the last two years, and
- Demand increased in other regions and countries (especially China, Mexico, and the Middle East).

Figure 4-15 shows more-recent trends in residential propane prices during the winter heating season from October 2002 to March 2003. During this period, the average residential propane price in the U.S. increased from a low of about $1.27 per gallon to a peak of about $1.70 per gallon at the height of the winter heating season in January 2003. At the end of the 2002-2003 heating season, residential propane prices decreased back down to the vicinity of $1.35 per gallon. The federal Energy Information Administration only tracks residential and wholesale propane prices during the winter heating season. Presumably, if propane becomes a major transportation fuel, prices by individual states would be reported on a year-round basis. Not much information is publicly available about how the seasonal demand and price fluctuations of the residential propane market might affect future transportation markets.



Source: Energy Information Administration

Figure 4-15. Recent U.S. Residential Propane Prices (Winter High Case).

At the peak for propane prices during the first quarter of 2003, the National Propane Gas Association (NPGA) released a press release[164] entitled "What's Behind Rising Propane Prices?" NPGA noted that several factors had "all dramatically converged at once" to push up the price of propane, as well as other heating fuels. The factors cited were:

- A colder-than-expected winter,
- Fears of war with Iraq,
- The reduction in crude oil supply from Venezuela, and
- Natural gas price spikes.

As previously noted, only very small volumes of propane are currently sold as motor vehicle fuel in California. Taxes (currently totaling about $0.28 per gallon) are applied to propane used for this purpose, as with other transportation fuels. The price of automotive propane has experienced trends similar to those shown above, with recent prices settling back down to post-winter levels. Spot checks of several stations in May 2003 indicated that the untaxed retail price of automotive propane is currently $1.10 per gallon, or about $1.38 per gallon fully taxed.[165] On an energy basis, this is equivalent to gasoline at about $1.88 per gallon, which was roughly the price for regular unleaded in California during the same time period. Like other motor fuels, discounts on the price of propane may be available to fleets depending on how much fuel they use and other factors. For example, a state tax exemption of $0.06 per propane gallon can be obtained through the State Board of Equalization. Or, an annual flat rate fuel tax ranging from $36 for vehicles under 4,000 lbs. to $168 for vehicles over 12,001 lbs. can be substituted. However, the breakeven point for these types of programs can require driving a propane vehicle for at least 30,000 miles annually.[166]

Propane prices are significantly lower when dispensed for automotive use, compared to refilling portable tanks such as those used for barbecues. For example, on the same day that motor vehicle propane was selling at $1.38 per gallon at a Delta Liquid Energy Station in Paso Robles, the station was selling propane for portable containers at $2.36 per gallon (both fully taxed).[167] Like other fuel suppliers, the propane industry is willing to offer significant price breaks as a function of the volume purchased and how much manpower is required to assist customers.[168]

Station Capital Costs

Figure 4-16 compares the costs of building three types of public-access LPG stations for automotive applications. It shows that a stand-alone dispenser with point-of-sale networking costs about $30,000. If the LPG dispenser is built onto the gasoline island at a typical station, the cost is about $70,000. The same station with a 6,000-gallon, below-ground LPG tank would cost about $100,000. At $31,000 to $92,000 per station, the costs of upgrading or building 13 new automotive-LPG stations in California with cost sharing from the Energy Commission) fall within these ranges.[169]

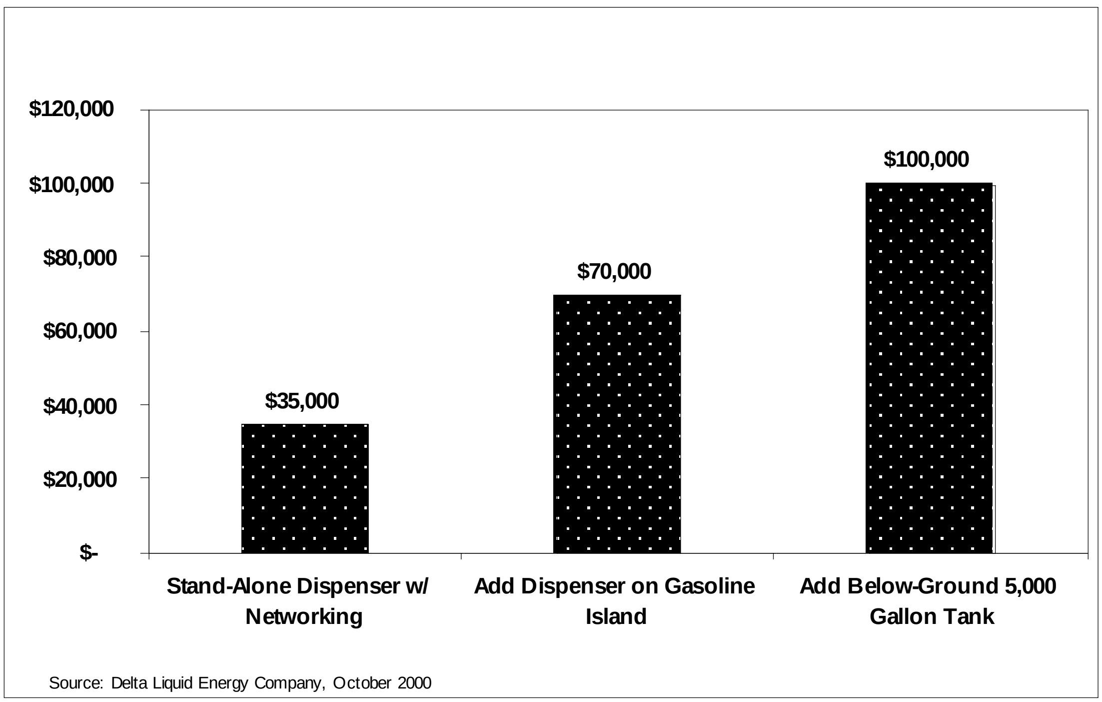


Figure 4-16. Estimated costs to build various types of LPG stations

Station Operation, Maintenance and Training

LPG stations are relatively simple systems compared to CNG or LNG stations. A typical station consists of an aboveground storage tank, a two to four horsepower transfer pump, and a meter and hose dispensing system. Unlike CNG stations, there is no need for a gas compressor or dryer. This makes an LPG station relatively easy to operate and maintain.

The estimated cost per year to maintain a station is $1,000, according to Delta Liquid Energy Company.[170]

Fuel Quality

LPG comes in three different commercial grades, with varying compositions of propane other hydrocarbons, and miscellaneous other constituents. A minimum propane content of 90 percent by liquid volume (HD-10) is necessary for automotive applications, to ensure sufficient vapor pressure for delivery of the fuel to the engine, even at very low temperatures.[171] From an emission standpoint, the propylene (also known as propene) content of LPG is of concern because it has high photochemical reactivity. Propylene does not occur in LPG obtained from natural gas processing plants, but it does in the LPG resulting from petroleum refinery operations. Primarily to control propylene content, the U.S. propane industry and regulatory agencies have developed an automotive propane standard known as HD-5. Fuel for spark-ignition engines in California must comply with this HD-5 specification, which is summarized in Table 26.

Table 26.
HD-5 Specification for Automotive LPG

Parameter	HD-5 Propane Specification
Propane Content	90% liquid volume (min)
Propylene Content	5% liquid volume (max)
Butane and Heavier HCs Content	2.5% liquid
Moisture Content	Dryness test of NGPA
Residual Matter Content	0.05 ml
Total Sulfur Content	123 ppm by weight fraction

Public Access: Hours and Accommodations

To date, most public propane stations have not been built for automotive fueling applications. As noted, the Energy Commission is working with Caltrans and other agencies to install 13 new automotive propane stations in close proximity to the state's fleet of bi-fuel propane vehicles. These stations are being designed primarily for fleet access using fueling cards such as Voyager. Some of these new stations are likely to provide 24-hour public access, seven days per week. Similar to other alternative fuels, the propane fueling network will ultimately need to include more user-friendly point-of-sale options, such as in-pump cardreader systems that accept personal credit cards.

Building Codes and Standards

LPG stations must meet a variety of codes and standards, including but not limited to UPC, UFC, UBC, and NFPA 58. According to survey input from one TAG member, the need to comply with variable requirements from local fire authorities is a major challenge to building and installing LPG stations. This problem is not unique to propane, as other types of alternative fuel stations have faced similar region-to-region variation with permitting and safety requirements. In part, it is the result of fire marshals being less familiar with the characteristics of alternative fuel stations compared to gasoline and diesel stations.

Time Horizon for Full Technological Maturity

A big challenge for expanded deployment of propane fueling stations and vehicles continues to be the limited number of OEM offerings for dedicated propane-fueled vehicles and engines, which may continue to hinder wider commercialization. As Table 27 shows, the average propane station in California currently dispenses only about 1,000 gallons of propane per month, and most of this is for non-automotive applications such as barbecues and heating. A 15-fold increase in throughput per station is reportedly needed to achieve commercialization goals for automotive station applications.

Table 27.
Projected need for expansion of propane vehicle fueling stations in California.

Market Element	Current	Projected Future Need
Number of Automotive LPG Stations	~19 (for vendor)	At least 18 more
Approximate LPG gallons pumped per month, per station	1000 (very little for automotive use)	14,000 to 15,000
Approximate GGE pumped per month, per station	700 (very little for automotive use)	10,000 to 10,650

Source: survey input from Delta Liquid Energy, updated for new stations expected to be operational by 12/03

As noted, 13 new propane stations are being built in California for automotive applications, in part through Energy Commission funding. In the near term, these stations will help state agencies such as Caltrans to utilize propane instead of gasoline in their fleets of bi-fuel pickup trucks. Equally important, these new stations increase the density of propane stations in California, which can provide greater confidence to vehicle and engine manufacturers that propane-fueled product offerings should be expanded.

Summary of Major Barriers and Impediments

As previously noted, the propane infrastructure has essentially already reached sustainable commercial status due to the fuel's use in non-vehicle applications. Automotive stations are more complex and costly than propane stations designed simply to fuel barbecue cylinders or forklifts, but they can be built at lower costs than natural gas stations (CNG or LNG). The biggest challenges to expanding the automotive propane infrastructure in California are related to vehicle and fuel issues more than the fueling stations themselves. Specific impediments include the following:

- High fuel prices and volatility due to distribution bottlenecks, storage imbalances, natural gas market dynamics, and other factors,
- Low demand for propane as an automotive fuel, due to lack of commercially available dedicated propane vehicles, and the absence of fuel-use requirements for bi-fuel vehicles, and

- High incremental cost (especially in the heavy-duty sector) of propane-fueled vehicles and engines.

4.3 Electric Vehicle Recharging Stations

As previously discussed in Section 3.1.3, the role that on-road battery EVs are expected to play in California over the next five years and beyond is less certain today than in 2001, due to modifications to the ZEV regulation that were adopted by CARB in April 2003. Over the last several years, EV charging stations have been installed throughout California under programs sponsored by the Energy Commission, the Mobile Source Air Pollution Reduction Review Committee (MSRC), and other organizations. Both public and private investors have established a skeletal network of EV recharging stations in the major regions of the state. Most new activities of this kind, however, appear to be on hold.

Much of the information presented below on the EV charging infrastructure was obtained through TAG input in 2001. No information was provided for this 2003 update regarding the extent (if any) that installed charging stations have become non-operational, or have since been removed.

Number of Stations

Survey responses were received from two TAG members in 2001 regarding the EV charging infrastructure. These estimates indicated that there were nearly 3,300 EV chargers California by mid 2001. About 59 percent were inductive chargers and 41 percent were conductive. Virtually all these charges provided Level II charging designed for 208 or 220 VAC power sources.

It is unclear how many of these 3,300 chargers cited in 2001 are still operational. Checks in mid 2003 of web-based AFV fueling station locators (e.g., cleancarmaps.com and afdc.doe.gov/refueling) indicated that 500 to 800 public-access EV charging stations (inductive and conductive) are currently operational in California. For example, Clear Car Maps indicates that there are 126 inductive small paddle stations, 364 inductive large paddle stations, and 297 conductive stations.

California's existing network for on-road EV charging evolved to serve the state's largest concentrations of battery-electric vehicles. Consequently, stations are concentrated in three major areas of the state: the Los Angeles Basin, the North and South Bay Area, and Sacramento.[172] Within these regions, charging sites are generally located in places where people spend time, rather than along major thoroughfares (e.g., interstates).[173] This is because current-technology EVs require significantly longer time to "refuel" compared to conventionally fueled vehicles, or other types of alternative fuel vehicles. The basic strategy has been to install chargers at key locations within metropolitan areas, allowing EV users to extend vehicle range through "opportunity" charging while shopping, attending sporting events, going to movies, etc.

In addition to the EV charging stations that are located throughout California at public agencies and private businesses, approximately 726 private residences in California have been wired for EV charging (as of 2001; see). The capability to "refuel" EVs at home is a significant advantage compared to using conventional vehicles.[174]

Existing and Needed Electricity Use Per Charger

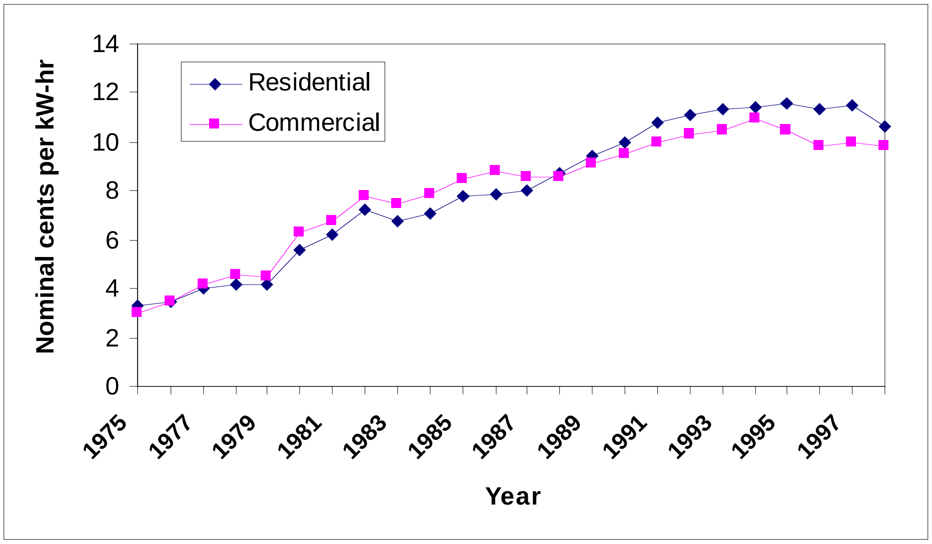
Little information is publicly available about the quantities of electricity currently used at California's on-road EV charging stations (per station, and collectively), or the quantity needed to justify installation and operational costs. At this early stage of EV deployment, public stations do not receive enough use to consume large quantities of electricity. Fleets with large numbers of EVs, such as Southern California Edison's Toyota RAV EV fleet, have experienced high electricity consumption per charger, and substantial quantities of gasoline fuel have been displaced.

As previously mentioned, there are 300,000 non-road EVs operating in California today with a total electrical load of more than 800 megawatts. This could grow to more than 2,000 megawatts by 2010. This significant load could be mitigated by load management and energy efficiency efforts.[175]

Electricity Demand, Supply and Price

The cost of electricity in California depends on local utility rates and other factors. For EV charging, there are a variety of rate structures. Residential EV charging rates range from $.04 to $.12 per kWh for off-peak charging, with on-peak charging costing substantially more. Also, electricity prices and charging rates change with the seasons and additional time-of-use and demand charges may be applied. To take full advantage of special off-peak EV charging rates, residential customers may need to install a second meter or a dual-meter adapter. As an example, the Sacramento Municipal Utility District (SMUD) has offered an EV charging rate that is approximately half the regular residential rate. To take advantage of the EV charging rate, SMUD requires that an additional meter with a dedicated EV charging outlet be installed at the residence. Southern California Edison offers its residential customers two "time of use" EV charging rates, depending on their individual charging needs and habits.

Figure 4-17 shows the historic average of electricity rates in California for residential and commercial customers from 1975 to 1998. Since electricity restructuring took effect in 1998, significant changes have been occurring in the supply and pricing of electricity. During late 2000, electricity supplies in California reached near-crisis levels and several emergencies were declared, even though demand was significantly lower than that of the summer peaks. While the crisis stage of this problem has since subsided, significant issues with electricity supply (and therefore price) may persist in California. A 2002 study by the Energy Commission concluded "California may face a rare combination of unfavorable circumstances that could bring risks of power supply shortages (in the form of lower than required reserves or even outages)."[176]



Source: California Energy Commission

Figure 4-17. Avg. Residential & Commercial Electricity Rates (California, 1975-1998)

However, as Figure 4-18 indicates, the forecasted system average electricity rates from California's major utilities show a general trend of stability over the next decade, with prices even *decreasing* at some major utilities.[177]

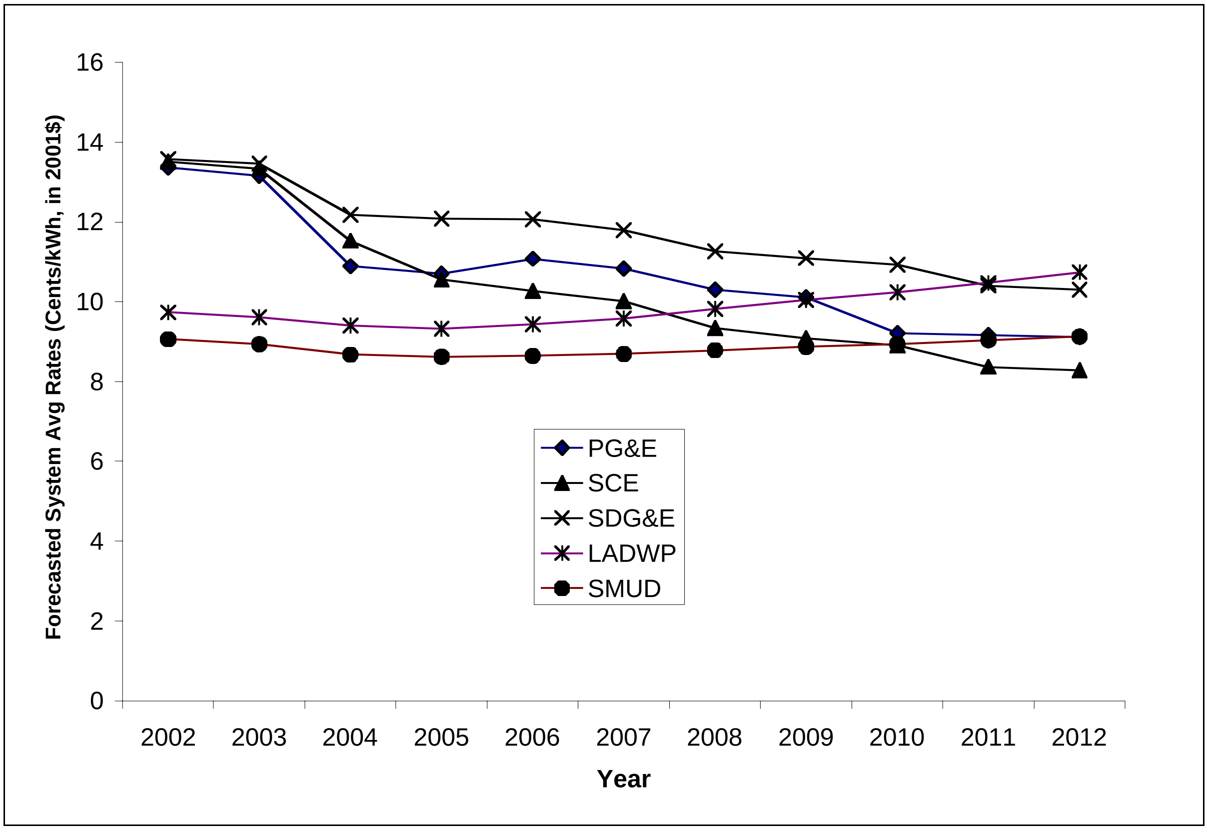


Figure 4-18. Forecasted System Average Electricity Rates ($2001) By Major Utility

According to the California Electric Vehicle Coalition, these current and forecasted electricity prices indicate that load management programs could provide real economic benefits to ratepayers and customers, by shifting future EV charging to off-peak hours and reducing consumption through energy efficiency programs.

Capital Cost of EV Charging Stations

The cost of non-residential charging stations for on-road EVs can vary significantly. In 2001, a typical Level II inductive charger cost about $2,200, while a comparable conductive charger cost from $800 to $2,100 (not including mounting hardware and shipping).[178] The total cost including installation at a new construction site (i.e., where cable and conduit can be laid during the building process) ranged from $5,000 to $7,000. Total costs as high as $10,000 could result in situations involving retrofit of a charger at an existing site, or if long trenches are needed to hook up with the source of electricity.[179] Significant cost reductions could be obtained when installing multiple chargers at the same site.

The cost of a residential charging station including installation was approximately $1,500 in 2001. At that time, CARB staff estimated that costs could be reduced by about 50 percent within a few years. One means to reduce future costs has been the adoption of local ordinances that require new housing construction to include 220V wiring to an electrical panel in the garage. Several cities in both northern and southern California have adopted such an ordinance. This reportedly costs as little as $5 extra during the construction process, where it could cost about $200 to retroactively add a new panel in the garage. However, with the current uncertainty of the types and numbers of EVs that will be commercialized over the next several years, it's difficult to gauge the immediate motivation of cities to adopt such ordinances.

According to input from the California Electric Transportation Coalition in 2001, station owners have paid between 25 percent and 60 percent of the total costs for public on-road EV charging stations. In other situations such as fleet and retail EV use, infrastructure costs are correlated to the purchase or lease of EVs. Over the last several years, there have been programs throughout the state funded by the Energy Commission (Petroleum Violation Escrow Account), the federal Clean Cities Grant Program, and the Mobile Source Air Pollution Reduction Review Committee. However, the future of such programs is uncertain. For example, in September 2002 the Energy Commission discontinued its program to help buy down capital costs and installation associated with on-road EV charging stations.

Station Operation, Maintenance and Training

EV charging stations are easy to operate and require no maintenance on the part of the end user. Training requirements are minimal.

Public Access: Hours and Accommodations

Hours of access to public charging stations vary. As a general rule, stations are available during the operating hours of the host site. Most public EV charging stations found in parking lots are available 24 hours. In the case of garages, operating hours are usually linked to working hours, e.g., 6:00 a.m. until 8:00 p.m.

Presently, EV charging is free to the user at public stations because the host site pays for the electricity. Thus, cardreader access and point-of-sale billing are not yet issues. Edison EV reportedly proposed a billing demonstration program, but it was never implemented. Some billing system and card system mechanisms have been tested, e.g., the Bay Area Rapid Transit's kiosk charging system. Development of user-friendly and cost-effective card reader systems for EV charging would become a priority if greater numbers of EVs are deployed over the next several years.[180]

Building Codes and Standards

EV charging stations must meet Article 625 of the 1996 California Electric Code. Building codes determine how the electrical code is implemented and set the standard for permit approval. In addition, EV charging stations must meet Interim Disabled Access Guidelines issued by the California State Architect's Division – the only fueling station type required to do so.[181] These existing standards and codes are updated as needed, based on technology changes and other factors.

Time Horizon for Full Technological Maturity

With the latest modifications made by CARB to the on-road ZEV requirement, it's doubtful that major automakers will make battery EVs commercially available before the 2005 model year. Based on actions and statements to date, they appear more likely to focus on producing advanced-technology, extremely low-emitting combustion vehicles that use gasoline. This includes today's hybrids -- as previously noted, today's hybrids currently require no special fueling infrastructure because they don't plug in or use alternative fuels. In the future, automakers may produce plug-in hybrids that offer the option to recharge the batteries from grid electricity, although no such plans have been publicly announced.

Essentially, the need to build more on-road EV charging stations in California is "on hold," along with battery EV elements of the ZEV program itself, pending resolution of litigation and other matters. At this time, investments in on-road EV charging stations may have inordinate risk to become stranded investments. Further complicating matters, General Motors has claimed that the "value" of its investments in inductive charger technology have been "severely" diminished because conductive charging has been selected as the state's EV standard.[182] This emphasizes the fact that new public investments in EV charging may be prudent only after the technological landscape becomes better defined, presumably over the next several years. However, it is important to emphasize that renewed efforts to deploy on-road battery EVs could quickly return in California under certain circumstances (e.g., advancements in low-cost, high specific energy battery technology, or new developments announced by CARB's expert panel). Each update of the Clean Fuels Market Assessment can revisit the issue of EV infrastructure and the proper role for government funding. For example, it's possible that new developments with neighborhood electric vehicles or plug-in hybrid electric vehicles will warrant further assessment of infrastructure requirements.

Summary of Major Barriers and Impediments for EV Infrastructure

There are a number of key barriers and impediments for expansion of the on-road EV charging infrastructure in California. The biggest relate to EV technology and not charging stations, as follows:

- Recent modifications made to California's ZEV program, which apparently will delay commercial introduction of battery EVs by major manufacturers until at least 2005.
- Competition from other vehicle technologies either becoming commercially available or meeting or nearing ZEV standards (e.g. fuel cell technologies, hybrids including gasoline and plug-in types).
- Ongoing technology limitations and cost constraints for on-road EV batteries.

While the above issues are of the most immediate concern, there are barriers more specific to charging stations themselves. In 2001, CARB staff released a report assessing and addressing some of these barriers. The report provided background on the status of public charging, EV charging technologies, safety standards related to EV infrastructure, infrastructure costs, and incentive programs related to infrastructure as well as recommendations for charger standardization. One broad recommendation, which has already been accomplished, was to establish a stakeholder-based EV infrastructure working group. Another completed goal (June 2001) was to standardize EV chargers. Other recommendations that may were made but may not have been accomplished are summarized in Table 29.

Table 29.
CARB 2001 staff report recommendations on EV infrastructure

Barrier / Issue	Recommendation
Limited public charging infrastructure	♦ Expand number of public stations, targeting "most critical" locations and applications
Improper use of EV charging spaces by non-EVs	♦ Develop local ordinances to discourage non-EV parking in spaces designated for EV charging ♦ Encourage enforcement of ordinances
Lack of information for EV users	♦ Develop centralized information center and improved mapping systems for EV users to keep abreast of where to find charging stations
Lack of EV charging stations at work locations	♦ Offer greater incentives and grants for employers to install EV charging stations ♦ Initially target locations having existing EV users as employees
Need for new / improved EV incentives	♦ Work with stakeholders to review effectiveness of existing incentives, and develop new incentives as needed
Impact of EV charging on the electricity grid	♦ Establish working group to further evaluate the issue and prepare relevant information
Source: California Air Resources Board, ZEV Infrastructure, January 2001	

Potential Further Assessments on EV Infrastructure

The previous version of this report included areas of potential additional research that could be conducted to assess what level of support, if any, the Energy Commission should allocate in the future for on-road EV infrastructure under the Alternative Fuels Infrastructure Program. Some of these assessments *may* still be useful, depending on how things develop over the next two years with the ZEV regulation, and the findings of CARB's to-be-appointed expert panel. For example, it may be useful to periodically reassess the role (if any) that EVs (including full-function EVs, neighborhood EVs and plug-in hybrids) can play in meeting the goals and objectives of AB 2076. However, no specific recommendations regarding battery EVs and infrastructure are made at this time.

4.4 E85 Fuel and Fueling Stations

Number of Stations in California

Thousands of E85 FFVs built by a variety of automakers are currently being operated in California (refer back to section 3.1.4 on page 37 for a list of available models). The FFV feature is standard equipment for many makes and models. Although these vehicles were designed to operate on E85 or any mixture of E85 and gasoline, there are currently no E85 stations in California. This means that today, nearly all E85 FFVs in California are being operated on gasoline.

In early 2003, the National Ethanol Vehicle Coalition (NEVC) issued a grant award of $46,300 to the California Department of Food and Agriculture and InterState Oil Company to develop an E85 fueling facility in the greater Sacramento area. The fueling facility will be owned and operated by InterState Oil and used to fuel E85 FFVs in the state's fleet. According to NEVC, two key objectives are to 1) promote the use of E85 to other FFV fleets, and 2) test the station's E85 dispenser equipment to verify compliance with California vapor recovery standards. Meeting vapor recovery standards in California is thought to present both a key challenge and a major opportunity for the E85 industry. NEVC hopes that this testing will lead to CARB's certification of E85 dispenser equipment, and thus the approval to open more E85 stations throughout California. [183] This important issue is discussed further below.

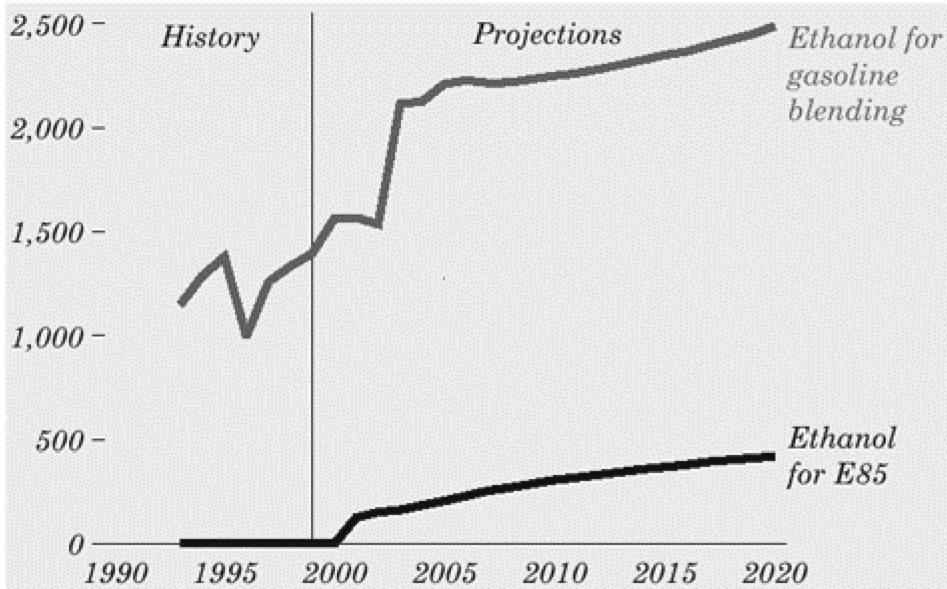
Outside California, approximately 157 stations in the U.S. dispense E85. Since corn is a primary feedstock for ethanol, it's not surprising that America's highest concentration of E85 use and fueling stations is in the Midwest corn-growing region. According to the U.S. Alternative Fuels Data Center, nearly half (71) of these E85 stations are located in Minnesota.

Existing and Needed Fuel Throughput

Currently, it is unknown how many E85 stations are needed to develop a self-sustaining E85 infrastructure in California, or the corresponding fuel throughput that would be needed at each station.

Fuel Supply, Demand and Price

U.S. fuel grade ethanol production reached 1.5 billion gallons in 1999, with corn serving as the primary feedstock. Demand in the same year was approximately 1.35 billion gallons.[184] Most of this was consumed in the transportation market through ethanol's use as a blending agent with gasoline, either to extend volumes of gasoline, or increase oxygenate levels to reduce wintertime carbon monoxide emissions from vehicles. Used in these ways, ethanol is considered a "replacement" fuel instead of an alternative fuel (per the U.S. Energy Policy Act). As Figure 4-19 shows, between 1.0 and 1.5 billion gallons of ethanol per year were blended into U.S. gasoline stock over the last several years; most of the resulting blend was sold in Midwest markets as so-called "gasohol." The federal Energy Information Administration projects that by 2020, the use of ethanol for gasohol or as an oxygenate will grow to about 2.5 billion gallons per year. This projection includes an increase in the expected role of ethanol as the preferred oxygenate for reformulated gasoline, since California and other states have passed legislation limiting or banning the use of methyl tertiary butyl ether (MTBE).



Source: Energy Information Administration, Energy Outlook 2001, December 22, 2000.

Figure 4-19. Past and projected U.S. ethanol consumption (millions of gallons)

The lower curve in Figure 4-19 shows the past and projected consumption trends nationwide for ethanol used to make E85 fuel for FFVs (see Section 3.1.4). The use of ethanol to make E85 has been very low compared to its use in gasohol. However, the federal Energy Information Administration projects that the U.S. demand for E85 will grow significantly over the next 20 years, and reach nearly 500 million gallons in 2020.[185]

During 2002, 1.4 billion gallons of MTBE were blended into California gasoline, while ethanol use was less than 100 million gallons.[186] Because ethanol is the only approved oxygenate to replace this MTBE, demand for ethanol in California (for all transportation applications) will increase significantly as MTBE is phased out of California's gasoline supply beginning in 2003.[187] It has been estimated that 560 to 580 gallons of ethanol will be required in California by the end of 2003 – about 20 percent of the 3 billion gallons per year currently produced in the U.S. Projections for California's ethanol demand in 2004 go as high as 990 million gallons.[188]

A recent report by the Energy Commission found that the transition to ethanol from MTBE is "progressing without any major problems" for California's refineries, with most refiners already using ethanol or in the process of changing. As of early 2003, roughly two-thirds of California's gasoline is now blended with ethanol.[189]

To date, ethanol provided to California has been from conventional feedstock such as corn. A report in March 2001 for the Energy Commission evaluated the costs and benefits of using biomass-based ethanol production in California to meet the oxygenate demand for California gasoline. The analysis was based on establishing 200 million gallons per year of ethanol production in California. Many positive attributes were identified to establishing a biomass-to-ethanol industry in California, including a finding that the economic benefits are potentially greater than the costs.[190]

Currently, the terminal market price of fuel ethanol[191] is approximately $1.10 per gallon. As see Figure 4-20 shows, this price has varied from a low of $0.90 per gallon to a peak of about $1.50 per gallon over the last 18 months.

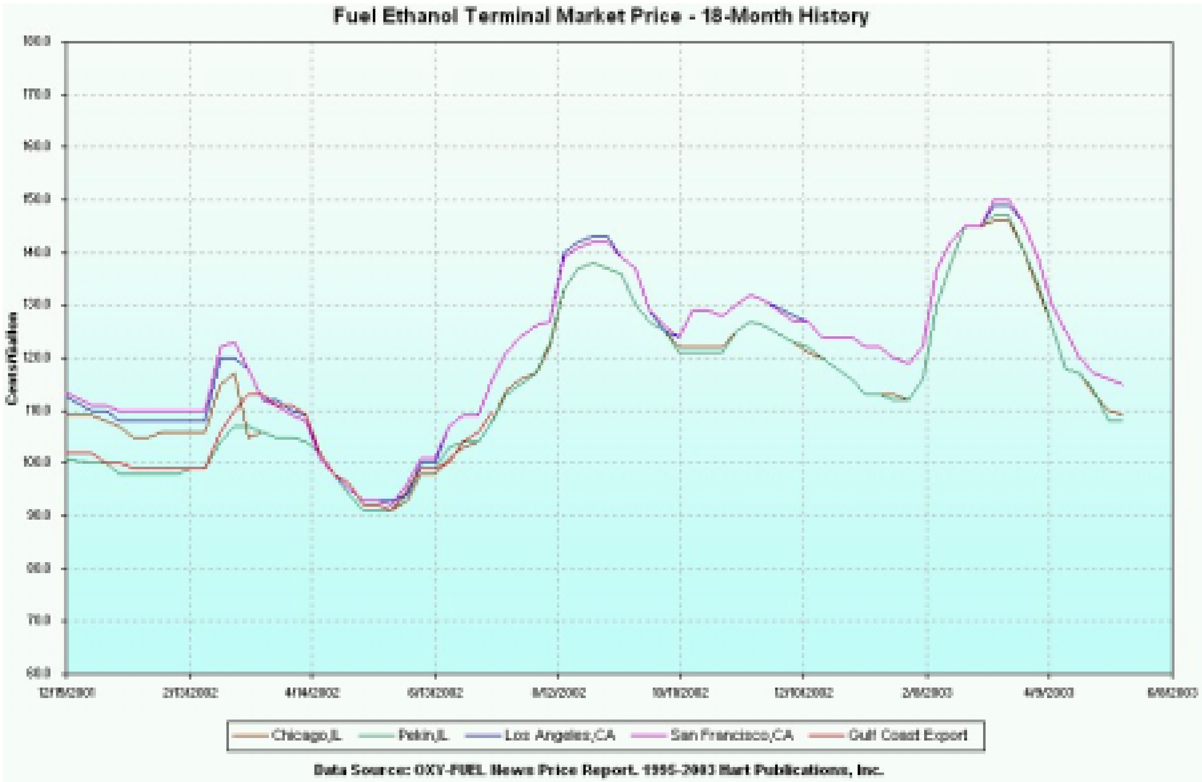


Figure 4-20. Recent Price Trend for Fuel Ethanol

The price trends shown above are largely responsible for determining the price of E85, the alternative fuel designed for today's commercially available FFVs. Historically, in those states where it can be purchased, E85 is more expensive than gasoline on an energy-content basis. Specific details on the cost and price dynamics of E85 were not provided by the ethanol industry in preparing this report.[192] The website for the National Ethanol Vehicle Coalition states that E85 is "typically priced to be competitive with 87-octane gasoline"[193] but provides no further detail. Spot checks of three stations in the Midwest (May 2003) indicated that E85 pump prices range between $1.40 and $1.65 per gallon. On an energy-content basis, this is equivalent to a price between $1.97 and $2.32 per gasoline gallon.[194] Prices for regular unleaded gasoline at the same stations ranged from $1.49 to $1.59 per gallon. The price for E85 at NEVC's planned station in California is not yet known.

In the 2001 version of this report, it was noted that the price of E85 for use in FFVs could significantly increase in 2003, due to the increased demand for ethanol as an oxygenate in reformulated gasoline. However, an Energy Commission survey of the ethanol industry in late 2002 indicated that existing ethanol supplies should be "sufficient" to meet California's demand. A more recent assessment by the Commission concurred, finding that "earlier concerns about the adequacy of ethanol supplies have since diminished as the ethanol production industry has added significant capacity to meet California's annual demand."[195]

Another key finding was that "the recent increase in California's gasoline prices cannot be attributable to availability or cost of ethanol."[196]

Clearly, the use of ethanol in California and other states as a blending agent for gasoline will increase over the next 20 years. This may or may not significantly limit the national supply of E85, and its potential to become a significant transportation fuel in California. The more immediate issue for E85 is whether or not the ethanol industry plans to pursue and support a fueling station network in California to fuel thousands of FFVs that are being operated exclusively on gasoline. Some positive signs have recently occurred, e.g., the industry's recent announcement that one station will be opened soon. And, at least one major automaker supports building an E85 infrastructure in California. According to TAG input from Ford Motor Company, the State's large population of E85 FFVs justifies expending government funds to install pumps in several large California cities, specifically to "promote the use of ethanol."[197] Currently, however, no obvious commercialization path exists for an E85 fueling network in California.

Building Codes and Standards

E85 stations must meet similar codes and standards as M85 stations, although the fuel is less corrosive and therefore creates fewer materials-compatibility issues. A good source for codes, standards and other issues associated with E85 stations is Guidebook for Handling, Storing and Dispensing Fuel Ethanol, prepared by the U.S. Department of Energy (see http://www.afdc.nrel.gov/pdfs/ethguide.pdf).

For an E85 fueling network to be launched in California, it must be demonstrated that E85 stations can meet the state's tough vapor recovery regulations. In May 2003, CARB acknowledged that it had received "several inquiries" about the applicability of those regulations to E85 stations. The letter stated that certified vapor recovery systems are required for E85 stations, while also acknowledging a conundrum faced by the E85 industry: CARB has never certified such systems for dispensing E85. CARB cited "serious material compatibility issues" if E85 stations use existing (gasoline) vapor recovery systems, but stated that it "did not intend to discourage" development of new technology that could help deploy E85 stations in California. Specifically to help foster development of E85-compatible vapor recovery technology, CARB announced that it would grant a "limited number of Research and Development" approvals for "uncertified vapor recovery systems." The specific purpose would be "to allow an E85 proponent" to generate data to support the certification of vapor recovery systems that are compatible with E85.[198]

Time Horizon for Full Potential to Displace Petroleum Fuels

With approximately 172,000 E85 FFVs on the road in the state, and the numbers increasing each year, a strong base of vehicles to potentially purchase E85 already exists. The demonstration of one E85 station as an R&D project sanctioned by CARB represents a key opportunity for E85 proponents to demonstrate cost-effective vapor recovery and expand the E85 fueling network in California. Meeting vapor recovery requirements and overcoming other commercialization barriers for E85 in California will be challenging.

Summary of Major Barriers and Impediments

There are a number of key barriers and impediments for the E85 fueling infrastructure in California. These include the following:

- Current lack of any stations in California, with only one in the planning stages,
- Challenging requirements to meet California's vapor recovery regulation,
- High production and distribution costs relative to gasoline and diesel fuel,
- Lack of fuel-use requirements in the federal Energy Policy Act or federal Corporate Average Fuel Economy regulations,[200]
- Lack of ease moving ethanol through the existing petroleum product network to end-users, and[201]
- Competing demand and economics to use ethanol as an oxygenate in reformulated gasoline.

4.5 Methanol Fuel and Fueling Stations

Number of Stations in California

Methanol is a liquid fuel made from natural gas or renewable biomass resources. At its peak use, M85 fuel (85 percent methanol blended with 15 percent gasoline) was sold at more than 60 facilities around California, most of which were public-access stations. During the same period, several transit districts converted one or more on-site diesel pumps over to neat methanol (M100) stations. Most notably, the Los Angeles County Metropolitan Transit Authority operated several M100 facilities to fuel approximately 330 methanol buses (equipped with Detroit Diesel 6V92 engines). The Energy Commission developed a "California Fuel Methanol Reserve," and entered into cooperative agreements with certain oil companies to dispense competitively priced methanol for at least 10 years. However, with no certified methanol vehicles on the market today, only a fraction of California's M85 and M100 fueling stations remain operational.

However, there is one methanol station located at the California Fuel Cell Partnership headquarters in Sacramento that may offer a glimpse into the future of methanol as a transportation fuel. Methanol is relatively easy to "reform" into hydrogen with onboard systems, methanol may re-emerge as a transportation fuel in California. Based on announcements made through the California Fuel Cell Partnership and by individual automakers,[202] it appears possible that within a decade commercially available light- and heavy-duty vehicles will be powered by fuel cell engines using methanol[203] reformate. Methanol producers expect to be able to meet the fuel demand if these fuel cell vehicles come into widespread use. However, there will be many retail-level issues to resolve. The most likely scenario for developing a methanol fuel distribution system would be similar to what already occurred in the 1980s and early 1990s, i.e., utilizing the existing gasoline distribution system by adding methanol-fueling capacity to retail gasoline outlets. This would require making sure that station components such as storage tanks, piping and dispensers are methanol compatible.[204] In addition, fuel cell vehicles using methanol (reformate or direct methanol systems) will require high-purity methanol (M100). Technical and safety issues must be overcome before M100 can be sold as a mainstream transportation fuel to the general public.[205]

Existing and Needed Fuel Throughput

Methanex Corporation, a global leader in methanol production and marketing, estimates that widespread acceptance of methanol fuel cell vehicles will require about 10 percent of California's fueling facilities dispensing the fuel. This would roughly equate to 950 methanol stations statewide. Locations of these stations would need to be coordinated with the heaviest concentrations of fuel cell vehicles, i.e., in the Los Angeles, Sacramento, San Diego, and San Francisco metropolitan areas. Methanex indicated that "many factors must be considered to estimate the fuel volumes per station," including number of user vehicles, geography and distribution system efficiency.[206]

Methanol Supply, Demand and Price

Methanol is sold as a chemical commodity and priced accordingly. Spot prices from various worldwide sources indicate that methanol sells at $0.73 to $0.85 per gallon in mid 2003. On an energy basis, this is equivalent to gasoline at about $1.47 to $1.71 per gallon.[207] The long-term price of methanol (2010 time frame) will be a function of many factors (e.g., the cost of natural gas feedstock, methanol surpluses resulting from MTBE phase-out), but projections from government sources indicate that it should be competitive with gasoline on an energy equivalent basis.[208]

As previously noted a consortium has been established to determine methanol fuel specifications for fuel cell vehicles. Additionally, testing of fuel cell systems is being conducted using various grades and combinations of methanol, and potential fuel additives. These results will be utilized in determining the quality of methanol fuel that must be delivered to fuel cell vehicles.

Station Capital Costs

Based on the M-85 station experience in California, the next-generation of methanol stations (i.e., M-100 most likely focused on fuel cell vehicle applications) will be very similar to today's gasoline fueling stations, having the same layout and employing the same types of equipment. However, before M-100 can be dispensed as a commercial fuel for vehicles, a number of safety and logistical issues will need to be addressed. These include: lack of flame luminosity, safety of flammable vapors in storage tanks, prevention of ingestion, safe handling by the public in a self-serve environment, and managing corporate liability.

According to a 1999 study performed for the methanol industry by EA Engineering, Science, and Technology, Inc., the capital cost of adding methanol storage and dispensing capabilities to an existing gasoline station is about $62,400. This retrofit consists of installing a new double-walled underground storage tank, and methanol-compatible components such as product and vapor piping, dispensers and valves. Where space is available and local codes allow, an above-ground tank can be installed, reducing the overall cost to around $54,600.[209] If an existing gasoline or diesel underground tank is already double walled and methanol compatible,[210] it can be cleaned and converted for methanol storage. This lower-cost option would still require installing methanol-compatible piping and dispenser equipment.

Time Horizon for Full Technological Maturity

The strongest indications that commercial "re-deployment' of methanol fueling stations may occur in California over the next decade are the methanol-related activities of the California Fuel Cell Partnership and its individual members. One associate member of the Partnership, Methanex Corporation, is a member of the Energy Commission's TAG, and responded in October 2000 to a fueling infrastructure survey. Table 30 summarizes key input received from Methanex, which may still be relevant for inclusion in this 2003 update.

Table 30.
Summary of survey input from Methanex on methanol infrastructure

Expected Timeframe for Full Commercialization	Number of Methanol Stations Needed in California	RD&D Activities and Plans
♦ No estimate given for full commercialization of methanol fuel cell vehicles or corresponding fueling infrastructure ♦ Initial deployments expected in 2004.	♦ Approximately 10 percent of today's retail fueling stations for vehicles ♦ Level of throughput needed at each station for commercial success depends on many factors	♦ Associate member of the California Fuel Cell Partnership ♦ Partnership will demonstrate different types of FCVs in the Sacramento area and "appropriate refueling mechanisms" in 2002 and 2003 timeframe ♦ Also supporting fuel cell demonstration activities in Europe and Japan ♦ Co-operative agreement with Statoil and XCELLSIS to evaluate commercialization needs

Methanol Infrastructure RD&D Activities

Through its involvement in the California Fuel Cell Partnership, the methanol industry is currently demonstrating one M100 station in Sacramento for fuel cell vehicles. The industry has been involved in efforts to prepare for deployment of more fueling stations, if and when methanol fuel cell vehicles are made commercially available. For example, in 2001 Methanex Corporation, Statoil and XCELLSiS[211] announced a co-operative agreement to evaluate how to commercialize methanol fuel cell vehicles. Under this agreement, health, safety, environmental and infrastructure issues associated with the use and introduction of methanol fuel cell vehicles were to be evaluated.[212] However, as of mid 2003 it is unclear if this collaboration is active. Recent developments within the Partnership and among various automobile companies suggest that fuel-related RD&D activities for fuel cell vehicles are now being focused on hydrogen more than methanol. The known exceptions are Daimler-Chrysler's NECAR 5 and the Georgetown University Fuel Cell Bus Program. Thus, RD&D activities associated with methanol infrastructure also seem to be dormant.

Summary of Major Barriers and Impediments

Currently, there are no confirmed public methanol stations operating in California, although there may be some stations operating for private-fleet applications.[213] The biggest barrier to a resurgence of California's methanol infrastructure is that no major vehicle manufacturers are currently selling on-road vehicles that use methanol fuel.[214] This situation may change over the next decade, since some major auto manufacturers are working on fuel cell vehicle

R&D programs that include methanol reformer systems. If methanol becomes a preferred fuel for such vehicles in California, methanol stations will be needed in proportion to the number of fuel cell vehicles deployed. Methanex estimates that up to 1,000 neat methanol stations will be needed in California to support the early years of commercialization. The California Fuel Cell Partnership includes participation by organizations with vested interests in building methanol stations for this purpose, but it remains to be seen if and when a methanol infrastructure will come to fruition. A key challenge relates to the magnitude of investments that would be needed for a methanol station network versus its useful life. Some fuel cell vehicle advocates would support methanol as a transition fuel until a widespread commercial and economically sustainable hydrogen infrastructure system can be established (see next section). A key advantage is that methanol infrastructure would be much less expensive to establish than hydrogen infrastructure. The debate relates to whether such transitional methanol infrastructure would have an economic lifetime sufficient to justify the investment.

4.6 Hydrogen Fuel and Fueling Stations

Number of Stations

As of mid 2003, there are only a few facilities in California specifically designed to dispense hydrogen as a motor vehicle fuel. Examples include the two different systems used by Sunline Transit to fuel its direct-hydrogen fuel cell bus in the Coachella Valley, American Honda's station in Torrance, and the California Fuel Cell Partnership's station at its headquarters in West Sacramento. Under the current system in West Sacramento, liquefied hydrogen is trucked in and stored in a 4,500 gallon on-site storage tank. Next, a vaporizer converts the liquid hydrogen to gaseous hydrogen, and a compressor raises the hydrogen gas pressure to 6,250 psi. Three ASME-type storage tubes are used to store the compressed hydrogen. Two dispenser systems deliver the compressed hydrogen to vehicles at either 3600 or 5000 psi depending on vehicle requirements.[215]

Although progress is now coming at a more rapid pace, today's hydrogen stations for vehicle applications remain essentially customized conversions of natural gas stations (CNG or LNG). It's conceivable that they bear little resemblance to how optimized hydrogen stations of the future will look or operate.

Existing and Needed Fuel Throughput

Throughput at the few existing stations in California that dispense hydrogen fuel for vehicles is very small, and currently insignificant in terms of petroleum fuel displacement. Although estimates have been made for numbers of direct-hydrogen fuel cell vehicles in California over the next decade (see page 40), it is premature to determine the necessary volumes of hydrogen needed to sustain a hydrogen fueling infrastructure in California.

Hydrogen Supply, Demand and Price

Hydrogen, the simplest and lightest fuel, is the most abundant element on earth. However, hydrogen normally occurs in a bound state with other elements and requires relatively large amounts of energy to extract it from compounds such as water and natural gas. Hydrogen is considered a renewable energy source, and supply is not expected to be a problem, at least in terms of available feedstocks.

Because hydrogen is in a gaseous state at atmospheric pressure and ambient temperatures, its use as a transportation fuel presents greater transportation and storage challenges than liquid fuels. Similar to the case with natural gas fuel, there are a variety of approaches used to produce hydrogen and store it onboard vehicles. These include the following:

- Off-site steam methane reforming of natural gas, with tanker-truck delivery of liquid hydrogen to the refueling station, and on-site storage of liquid and gaseous hydrogen,
- On-site natural gas reforming, with on-site compression and storage of gaseous hydrogen, and
- On-site electrolysis (splitting of water into hydrogen and oxygen), with on-site compression and storage of gaseous hydrogen.

The "best" method for vehicle applications is yet to be determined and depends on the intended application, as well as many other factors. As noted discussed in Section 3.2.2, the first commercial direct-hydrogen fuel cell vehicles in California are likely to be transit buses, deployed at transit districts that have chosen the "diesel" path under CARB's transit bus fleet regulation. Transit agencies that deploy a small number of fuel cell buses may choose to follow the Chicago Transit Authority model, i.e., where liquid hydrogen is produced at a large centralized plant, and then trucked to the transit agency's on-site fueling facility for storage. Liquid hydrogen is then pumped and vaporized for storage on the bus, similar to the process used at today's "L/CNG" stations.

A second alternative would be to follow British Columbia Transit's model, and use on-site electrolysis to produce hydrogen. This option may warrant further study where there is an abundance of renewable energy to power the electrolysis process, as is the case in British Columbia (hydroelectric power) and the Coachella Valley of Southern California (wind and solar power). For the electrolysis option, as the hydrogen is generated it is compressed and pumped into storage tanks on each fuel cell bus. Another possibility would be to use on-site generation of hydrogen using a small-scale methane reformer. Both of these latter methods for generating hydrogen have been demonstrated at Sunline Transit Agency in Thousand Palms, California, in conjunction with the California Fuel Cell Partnership.

Regardless of how it is produced, hydrogen for fuel cell applications needs to be free of impurities (e.g., sulfur). Fuel standards will need to be adopted before significant numbers of fuel cell vehicles are deployed.

Currently, hydrogen costs about $5.00 per gallon, which is three to four times more expensive than gasoline. Long-term cost and pricing studies for hydrogen as a transportation fuel have been performed by a variety of entities, including but not limited to Directed Technologies and Princeton University.[216] The price of hydrogen as an automotive fuel will be a function of many factors, including the following: 1) cost of feedstocks such as natural gas and methanol, 2) technology and related costs for the fuel production process (e.g., methane steam reforming, solar electrolysis, hydroelectric electrolysis), 3) proximity of feedstock supply, and 4) specific issues within individual markets served. It is generally accepted that the price of hydrogen fuel will be significantly higher than gasoline and diesel fuel in the early years of fuel cell vehicle deployment. A goal of the U.S. DOE is to reduce the cost of hydrogen to $1.50 per gallon (gasoline equivalent) by 2010. This assumes the hydrogen would be produced from natural gas or a liquid fuel such as methanol.[217]

Station Capital and Operational Costs

The capital costs of hydrogen stations are not fully known at this time. Station designs are beginning to emerge, but mostly as early concepts, and few hydrogen-specific codes and standards exist. Capital costs will depend in part on whether a liquefied hydrogen or compressed form of hydrogen will be stored and/or produced at the station. In either case, costly fire and safety requirements are likely to be the norm at hydrogen stations, at least in the early years of deployment. In 1998, it was estimated that the costs of hydrogen fueling stations for a typical 200-bus transit operation would likely exceed the current cost of large CNG stations (i.e., as much as $1.5 million).[218] Recent first-generation hydrogen stations built in West Sacramento and other areas under the California Fuel Cell Partnership indicate they cost between $2 and $3 million, at least in this early developmental stage.[219] Given that a large LNG station for transit bus operations can cost as much as $4.5 million when including all necessary site modifications,[220] it's likely that comparably-sized hydrogen stations will carry even higher price tags initially. Operation and maintenance costs for hydrogen stations are also likely to be at least as high or higher as comparable types of natural gas stations (i.e., compressed or liquefied gas).

It should be noted that unlike gasoline and diesel stations, hydrogen stations may *produce* hydrogen as well as store and dispense it. This must be taken into consideration when comparing station costs.

Building Codes and Standards

To date, few uniform codes and standards have been specifically designed for hydrogen vehicle fueling stations. This is one of the most challenging barriers to hydrogen becoming a mainstream transportation fuel. Currently, as early prototype hydrogen stations are built and deployed, existing codes and standards for similar facilities are being followed . For example, the compressed hydrogen station in West Sacramento "meets or exceeds safety standards set by the National Fire Protection Association (NFPA), the American Society of Mechanical Engineers (ASME) and other technical guidelines," including design standards found in the hydrogen industry website (www.ttcorp.com/nha). Dispensers for the compressed hydrogen are essentially CNG dispensers (meeting all codes) that have been modified for higher working pressures and other parameters. Ultra-violet / infrared systems are used to detect gas leaks and/or hydrogen fires.[221] In California, the California Fuel Cell Partnership and its individual members, including the Energy Commission and the SCAQMD, are being proactive to address such barriers. Nationally, the U.S. DOE is taking the lead and has drafted a <u>Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan,</u> which assigns high priority for addressing hydrogen safety and corresponding codes and standards.

The process is underway nationally and internationally to develop entirely new standards and codes hydrogen fueling stations. In the U.S., DOE has assigned the overall coordination and harmonization of these efforts to the National Renewable Energy Laboratory (NREL). A

Hydrogen Codes and Standards Coordinating Committee has been established to coordinate action items needed for this harmonization process. The U.S. Fuel Cell Council website (http://www.usfcc.com) contains a comprehensive listing of hydrogen and fuel cell codes and standards, although much of the information is restricted to USFCC members.

Time Horizon for Full Commercial Maturity

By 2010, DOE has established a goal to publish a hydrogen handbook of Best Management Practices for Safety, and complete U.S. adoption of a "global technical regulation" for hydrogen fuel cell vehicles and fueling stations. Generally, experts expect that it will take decades rather than years to achieve a commercially mature hydrogen station network in the United States, although California appears on its way to being an "early adopter." One 2000 report about the timeline for hydrogen fueling stations, *Blueprint for Hydrogen Fuel Infrastructure Development*,[222] states that there are no apparent "show stoppers" for technological advancement of hydrogen fueling stations that might prevent significant deployment of hydrogen fuel cell vehicles. In the words of the *Blueprint for Hydrogen* report, "the issue here is timing and coordination of capital investments." However, the magnitude of needed funding is very large, with few compelling reasons for private industry to make such investments, as long as petroleum fuels are abundant and affordable to the motoring public.

Hydrogen Infrastructure RD&D

The number of RD&D programs for hydrogen fueling infrastructure continues to grow. Examples of specific infrastructure programs currently in place (or planned for the near term) for California are listed in Table 31 and Table 32. A notable recent development was President Bush's pledge in January 2003 that the federal government will provide $1.2 billion towards hydrogen infrastructure needed for deployment of hydrogen powered - vehicles.

In California, the Energy Commission has been a leader in supporting collaborative efforts to build new hydrogen fueling facilities for fuel cell vehicles. Much of this is being done in conjunction with the California Fuel Cell Partnership. Specific types of support from the Energy Commission include:

- Provision of funding to support hydrogen fuel infrastructure demonstrations, and studies that can provide guidance for planning, designing, siting, permitting, and procuring facilities to refuel hydrogen-powered vehicles in San Jose (Santa Clara VTA), Oakland (AC Transit), and Chula Vista (Chula Vista Transit).

- Assistance with paths to fuel cell commercialization, from identifying potential problems associated with codes and standards, siting, safety, infrastructure, and fuel choice, to developing solutions to these problems.

- Increasing public awareness and enhancing opinion about fuel cell vehicles and hydrogen, to prepare the market for commercialization.

- Managing a study to assess and help overcome a variety of hydrogen fueling infrastructure issues (expected to be completed in the Spring of 2004).

- Managing a grant funded by the U.S. Department of Energy to collect data and do field verification work at Sunline Transit Agency on reformers that convert natural gas to hydrogen.

As a way to initiate a transformation from natural gas to hydrogen, one transit district is testing a transit bus on CNG with hydrogen added. SunLine Transit Agency has joined with Cummins Westport to test special buses fueled by a mix of 93% CNG and 7% compressed hydrogen (by energy content). The hydrogen component of the fuel helps to further reduce NOx emissions, compared to 100% CNG fuel. So far, good performance and a significant NOx emission decrease have been demonstrated using a revised engine calibration.

Table 31 provides additional details about these and other projects involving hydrogen infrastructure. Table 32 provides examples of other efforts that are in the planning stages.

Table 31.
Examples of current publicly-funded RD&D efforts to establish hydrogen fueling infrastructure in California

Program	Funding Level	Infrastructure Program Description
AC Transit Hydrogen Fuel Cell Bus Fueling Station Contract	$2.5 million to develop fueling station and make necessary facility improvements, with $925,000 provided by the Energy Commission	AC Transit has established a fueling station for fueling its direct-hydrogen fuel cell buses, which will be received in the 2004 time frame. Funds were specifically used to purchase equipment for the fueling station. AC Transit owns and operates the equipment. The station also fuels light-duty fuel cell vehicles from the CaFCP when they are being operated in the Bay area.
Chula Vista Hydrogen Production and Fueling Project	$1.06 million	The City of Chula Vista will demonstrate a portable electrolyzer developed by Stuart Energy. The portable unit will include the electrolyzer, storage tanks, compressor, and dispenser on one 40-foot trailer. It will dispense hydrogen into vehicles at up to 5,000 psi. (60 kg H_2 /day produced)
Los Angeles International Airport (LAX) Hydrogen Refueling Station	$115,000 provided by the Transportation Committee as a pass-through grant from DOE, SCAQMD committed $300,000	The Transportation Committee of the South Coast AQMD approved a pass through grant from DOE for a hydrogen fueling station at the Los Angeles International Airport. Fuel cell vehicles from Ford and Nissan are expected to use this new facility.
Santa Clara Valley Transportation Authority (VTA) Hydrogen Fueling Station	$300,000 in PVEA funds from the CEC to be used to purchase equipment only	VTA expects the hydrogen fueling station should be operational on or before August 30, 2003. The design will be a cryogenic hydrogen fueling and storage facility will be constructed to provide fuel for three fuel cell demonstration buses. CaFCP may also use this site as strategic fueling point.
SunLine Transit Agency Hydrogen Reformer Field Verification Grant	$470,000 From DOE, SunLine has about $487,000 in match-share contributions	SunLine has been awarded a DOE SEP grant to collect data on a natural gas-to-hydrogen reformer. Data will include costs, reliability, efficiency, safety and other factors. SunLine is a member of the Calif. Fuel Cell Partnership.
Energy Commission Hydrogen Fueling Infrastructure Study	$500,000	This project will conduct in-depth research, analysis and site visits on a wide variety of relevant hydrogen fueling related barriers. Research topics include: -Steps to developing a safe hydrogen fueling station -Failure Modes and Effects Analysis -Natural gas and hydrogen fueling station co-location potential -Long-term supply and demand issues with hydrogen -Technical paper on hydrogen fueling issues -Other related topics

In addition to those efforts above, a $10.8 million 5-year effort is underway in Las Vegas to demonstrate a "hydrogen energy station" that generates both hydrogen and electricity. This effort is being funded by the U.S. DOE, the City of Las Vegas, and various industry partners.

Table 32.
Future collaborative efforts to establish hydrogen fueling infrastructure in California

Collaboration	Expected Start
Toyota and Sunline Transit	2003
Sunline Transit and Stuart Energy	2003
UC Irvine and Stuart Energy 2003	2003
Torrance and Stuart Energy 2003	2003
Praxair and City of Ontario with SCAQMD	TBD
Davis	TBD

Summary of Major Barriers and Impediments

Major immediate barriers to wide-scale commercialization of hydrogen-fueled vehicles include the following:

- Cost to produce hydrogen,
- Lack of commercially available vehicles (internal combustion engine or fuel cell vehicles),
- Lack of low-cost, high-energy-content storage technology for hydrogen,
- Lack of capital currently to invest in optimized hydrogen fueling stations,
- Perception of hydrogen as being more dangerous than conventional fuels, and
- Need for new codes, standards and safety procedures for the use of hydrogen.

5. Conclusions and Recommendations

This section summarizes key findings and conclusions, and provides recommendations on possible future expenditures under the California Alternative Fuels Infrastructure Program.

5.1 Overview and Summary of Target Vehicles / Applications

The Program targets expansion of fueling infrastructure for alternative-fuel vehicles and applications that will displace the greatest volumes of petroleum fuels or hold promise to do so. Whenever possible, achieving quantifiable air-quality benefits is also an important objective. In addition to mainstream alternative fuels, a variety of "unconventional" liquid fuels (e.g., biodiesel, Fischer-Tropsch diesel) can potentially help California meet both objectives. However, the immediate infrastructure needs of such fuels are minimal or need further definition, compared to other alternative fuels. For the purposes of planning potential expenditures towards expansion of California's Alternative Fuels Infrastructure, candidate fuels assessed in this report include natural gas, propane, ethanol, methanol, electricity and hydrogen. Recommendations are provided for the most promising fuels and applications where both the need and the benefits have been clearly identified; for others, monitoring of progress and/or further assessments are suggested. Selection criteria for projects include the following:

1. Strong potential exists to help meet the petroleum displacement targets of Senate Bill 1170 and Assembly Bill 2076,
2. Key market and regulatory drivers exist to help ensure success,
3. A full complement of stakeholders and participants is involved to advance commercialization (e.g., engine and vehicle manufacturers, fuel providers, etc.),
4. Deployment and support of certified low- or zero-emission technologies will occur,
5. The fueling network will be expanded for end users in vehicle niches and applications that are strategic to long-term petroleum displacement efforts,
6. Collateral benefits may accrue, such as expanding networks of public-access stations, and facilitating station sharing among neighboring fleets, and
7. Risks to become "stranded" investments are as low as possible.

Related to this issue of minimizing risk is the question: *To what degree should government-supported alternative fuel stations be required to offer public access and networked card reader systems?* Clearly, major expansion of public-access stations will be needed in the long run to achieve a sustainable AFV market and maximize gasoline and diesel displacement. However, at this early stage of commercialization, stations most conducive to dispensing large volumes of fuel – a critical immediate objective – tend to be private or "limited-access" stations affiliated with large anchor fleets. To address this dichotomy, it is recommended that potential projects and applications be evaluated on a case-by-case basis before determining if public-access capability should be required. As one TAG member has suggested, retrofitting existing stations for public access is a viable approach, as long as those stations already have high throughput.

Currently, the heavy-duty vehicle sector offers the best opportunities to displace consumption of petroleum fuels and achieve air quality benefits. However, the emission competitiveness of diesel-fueled HDVs is likely to rapidly improve over the next five years. As such, it's difficult to predict the longer-term degree to which emission-related regulations will continue to drive AFV commercialization. This makes it even more important to immediately build momentum towards self-sustainable commercial AFV markets, while energy security drivers are complemented by air quality regulations and related incentives. Certain light- and medium-duty vehicle applications that entail high fuel use are also conducive to fuel displacement.

The Energy Commission's recent allocation of $6.0 million for alternative fuel infrastructure projects, including 41 natural gas and propane stations totaling about $5.1 million of state funding, is a major step forward towards the necessary infrastructure expansions. However, continued efforts are both needed and justified. The task to establish sufficient numbers of AFV fueling stations is significant. In the heavy-duty sector alone, tens of thousands of AFVs will potentially be deployed in California over the next decade, either to meet various government regulations or exploit incentive programs. In the greater Los Angeles area, fleet rules from the SCAQMD's 1190 Series are already helping to deploy AFVs, and thousands of heavy-duty AFVs are expected to require access to alternative fuel within a decade. In other parts of California, the CARB's transit bus fleet rule has helped to stimulate increased deployments of alternatively fueled transit buses at some of California's largest transit districts.

Near-term alternative fuels that continue to hold good promise to help displace petroleum fuels in these HDVs include natural gas (CNG, LNG, and L/CNG) and propane. Tens of thousands of heavy-duty NGVs will be needed in the western United States by 2010 to achieve a sustainable vehicle industry. Corresponding vehicle and infrastructure investments will cost hundreds of millions of dollars. Initially, at least, much of these funds will need to come from grants and incentive programs, to augment industry's share (approximately 75 percent).

5.2 California's Energy Horizon and Other Uncertainties

Beginning in mid 2000, California experienced a major crisis in its energy markets. Supply, demand and price for virtually all transportation fuel markets were affected. As of mid 2003, the "crisis" atmosphere has subsided for California's energy markets, but issues and problems persist. This report attempts to assess likely ways in which energy perturbations may impact potential AFV infrastructure projects, but comprehensive analysis is not within its scope. A basic assumption is that, over the longer run, further investments to diversify fuels in the transportation sector will help expand California's energy options and assist in achieving sustainable markets for non-petroleum alternatives.

A significant concern continues to be the rising demand for natural gas by electricity generators, which may constrain available natural gas supplies for the transportation sector, and may also further affect supply and price for other key fuels (e.g., propane). Based on the best available information as of mid 2003, it appears that supply and/or distribution problems for alternative fuels such as natural gas and propane may persist, perpetuating volatile prices that at times exceed those of conventional fuels on an energy-equivalent basis. At least one energy expert sees the winter of 2003 as an ominous sign for worldwide energy markets, with natural gas production in several key countries declining, oil and natural gas prices hitting all-time highs, and storage stocks for both commodities too low. On the other hand, long-term scenarios from both the Energy Commission and federal Energy Information Administration suggest that crisis levels can be avoided, even though energy demand in California will exceed supply, requiring more imported energy and increased in-state production.

Largely as a response to the 2000-2001 energy crisis and these types of projections, California has become more proactive over the last two years in efforts to develop indigenous sources for alternative transportation fuels. Still, continued progress is needed to reduce California's ~85 percent dependency on imported natural gas, currently transported in by pipeline deliveries or LNG shipments that remain fully subscribed. Potential strategies to augment California's supply of clean transportation fuels include further exploiting its large untapped resources of waste-to-energy technologies, and using emerging gas-to-liquids technology to extract waste and stranded reserves of associated natural gas. These activities are needed in addition to existing efforts to develop small-scale liquefaction plants to produce LNG, using pipeline gas or remote gas sources.

5.3 Recommendations for Future Support by Vehicle Application

The best use of funds for alternative fuels infrastructure will support end users and vehicle applications that meet the characteristics described above. Fleet applications that generally meet these characteristics, and therefore make good candidates for continued focus by the Energy Commission's infrastructure development program include the following:

- Refuse haulers,
- Transit buses,
- Class 8 trucks (return to base),
- High-fuel use LDV applications (e.g., large taxicab fleets), and
- High-fuel use MDV applications (e.g., airport shuttle buses, package-delivery services).

There are also potential AFV applications that may not currently involve high fuel use, but are capable of significantly advancing California's long-term potential to displace petroleum fuels. Such applications are also good candidates for future resource allocations in the "small to medium" category (roughly $65,000 to $250,000 per project). These include:

- School buses, and
- Small MDV and LDV fleets seeking "startup" operations with dedicated AFVs utilizing a single dispenser, or multiple vehicle refueling appliances (VRAs).

5.4 Recommendations for Specific Resource Allocations by Fuel Type

Taking into account the objectives, issues and criteria discussed above, Table 33 provides specific recommendations for funding allocations towards alternative fuel infrastructure activities. These recommended allocations are meant to be approximate; actual allocations will need to consider many factors, such as vehicle base and throughput, and the availability and timing of cost sharing from other sources.

Table 33.
Infrastructure activities recommended for highest priority of resource allocations

Station Type	Target Fleets	Specific Needs and Priorities	Approximate Recommended Allocation
LNG	Public and private refuse hauler companies, return-to-base delivery fleets,	• Cost-share new stations • Expand efforts to use small-scale liquefaction facilities and indigenous gas sources to produce LNG in California	TBD when funding identified
CNG	Transit districts with high to medium fuel use School districts and large, high-fuel-use LDV fleets	• Cost-share new station(s) for district(s) with highest fuel use and strongest commitment to CNG. Coordinate use of funds for CNG infrastructure with bus purchases under CARB transit fleet rule and California Lower-Emitting School Bus Replacement Program. • Cost-share new station(s) for taxi fleets or similar-use LDV fleets	TBD when funding identified
L/CNG	Mixed types of NGVs	• Cost-share new L/CNG stations in strategic locations for integrated use of LNG HDVs and CNG MDVs/LDVs	TBD when funding identified
LPG	High-fuel-use State and/or private fleets (including off-road applications)	• Cost-share optimized "beta" LPG stations focused on fleets with dedicated vehicles or large numbers of bi-fuel vehicles that will guarantee fuel use	TBD when funding identified
CNG or LPG	Small LDV or MDV fleets starting out with AFVs	• Cost-share sites that can use multiple VRAs or small fueling stations to fuel dedicated AFVs	TBD when funding identified
Total of Recommended Resource Allocations			**TBD**

A goal under the Alternative Fuels Infrastructure Program is to achieve approximately $4 of cost sharing for every $1 spent by the Energy Commission. Due to changes in the State budget and other key developments over the last few years, sources of potential cost sharing will need to be updated continually, as funding allocations become better understood.

5.5 Recommendations for Further Study and/or Monitoring of Progress

The following recommendations are made regarding other AFV types and their corresponding infrastructure.

5.5.1 Battery EV Recharging Infrastructure

With recent changes adopted in California's landmark ZEV regulation, it appears that new on-road battery EVs will not be commercially deployed before 2005. These modifications have introduced new uncertainty about the likely role for battery EVs in helping automakers comply with the regulation. It appears likely that automakers will focus on developing and commercializing advanced ICE technologies including hybrids to meet their obligations, to the extent allowed under the CARB program. Plug-in hybrids also have potential and are the favored platform of the electric utility industry, but as yet no support has been publicly announced by automakers.

While there remains a functional network of on-road EV charging stations in California today, the future for those stations and the deployment of new stations is as uncertain as on-road battery EV commercialization itself. However, it is important to emphasize that renewed efforts to deploy on-road battery EVs could quickly return in California under certain circumstances (e.g., advancements in low-cost, high specific energy battery technology, or new developments announced by CARB's expert panel). Each update of the Clean Fuels Market Assessment can revisit the issue of EV infrastructure and the proper role for government funding. For example, it's possible that new developments with neighborhood electric vehicles, non-road electric vehicles, or plug-in hybrids will warrant further assessment of infrastructure requirements.

5.5.2 Hybrid Electric Vehicle Infrastructure

As described in this report, hybrid electric vehicles (HEVs) are being developed that offer the advantages of electric drive (high efficiency and torque at low speeds), while providing performance, fuel economy and range equivalent or better than conventional vehicles. Hybrid types under development or consideration include grid-connected (plug-in) vehicles as well as those with low-emission ICE engines or microturbines. These vehicles have potential to help displace petroleum fuels in the near term as well as serve as a bridge to all-electric propulsion systems (e.g., fuel cells or advanced battery EVs). Since the infrastructure implications are not yet clear, no funding appropriations are recommended at this time specific to hybrids. However, progress should be closely monitored in annual updates of the Clean Fuels Market Assessment.

5.5.3 E85 FFV Infrastructure

Ethanol is now replacing MTBE as the new oxygenate in California gasoline. California refiners are well along in their phaseout of MTBE and transition to gasoline blended with ethanol. Earlier concerns about potential shortages of ethanol have been alleviated – it now appears that the extensive demand for ethanol as an oxygenate can be met by existing supplies (with expected growth) and distribution channels.

Flexible fuel vehicles with the capability to operate on ethanol (E85) or gasoline are widely available in California. As of April 2003 more than 172,000 E85 FFVs were registered in California, and the number could reach 220,000 by the end of 2003. Currently, E85 fuel is not available, and those FFVs are operated exclusively on gasoline. Switching to the use of E85 instead of gasoline in just a portion of the state's 172,000 E85 FFVs would move California significantly forward in meeting the longer-term petroleum displacement goals of AB 2076.

Recent developments point to renewed potential for E85 fueling stations to be introduced into the state. These include 1) the industry's announcement that at least one station will be opened, 2) CARB's willingness to work with the industry to develop suitable vapor recovery technology for E85 stations, and 3) the stated support from one major automaker for a modest E85 infrastructure in California. The E85 industry plans to use the first deployment as an R&D venue to demonstrate that E85 stations can meet California's tough vapor recovery requirements. Assuming this can be achieved, a major opportunity exists to build more E85 stations and begin displacing significant volumes of petroleum fuel in California's large fleet of E85 FFVs.

It is recommended that progress and development of the new E85 station(s) be carefully monitored to determine if vapor recovery requirements are met and a system can be certified by CARB. Based on the results that emerge at this station and any new developments within the ethanol industry, future Clean Fuel Market Assessment updates should revisit the appropriateness of allocating Energy Commission funds to ethanol infrastructure.

5.5.4 Methanol Infrastructure

Methanol is an excellent carrier of hydrogen for use in fuel cells, and can also work well in vehicles with internal combustion engines. Today there are less than 10 public M85 or M100 fueling stations in California. The biggest barrier to expanding this infrastructure is that no major vehicle manufacturers are currently selling on-road vehicles that use methanol fuel. This situation may change over the next decade, since several major auto manufacturers have been involved in RD&D programs involving methanol fuel cell vehicles. It is expected that additional information will be released through the California Fuel Cell Partnership, as it becomes available.

Methanol producers such as Methanex expect to be able to meet the fuel demand if these fuel cell vehicles come into widespread use. The most likely scenario for developing a methanol fuel distribution system would be similar to what already occurred in the 1980s and early 1990s -- utilizing the existing gasoline distribution system by adding methanol-fueling capacity to retail gasoline outlets. A consortium has been established to determine methanol fuel specifications for fuel cell vehicles, and assess commercialization issues. However, recent developments suggest that fuel-related RD&D activities for fuel cell vehicles have largely shifted away from methanol in favor of the direct-hydrogen approach.

Nonetheless, methanol continues to hold potential to be used in fuel cell vehicles, and at least two programs continue to pursue methanol reformate systems. Methanol infrastructure should remain a candidate for potential support under the California Alternative Fuels Infrastructure Program.

5.5.5 Hydrogen Infrastructure

Hydrogen is expected to be the long-term fuel for fuel cell vehicles. On strictly a demonstration scale, in certain niche applications such as transit buses, direct-hydrogen fuel cell vehicles are already displacing conventionally fueled vehicles. Over the last two years, there has been clear progress advancing the hydrogen-related programs of the California Fuel Cell Partnership and many of the various government and industry partners. On the infrastructure side, the Energy Commission has emerged as a leader, in general and through involvement with the California Fuel Cell Partnership. A variety of supporting programs have been initiated by the Commission, including an infrastructure grant of $300,000 to cost share a new hydrogen station at Santa Clara Valley Transit Agency. This kind of support is essential, because achieving widespread use of direct-hydrogen fuel cell vehicles will require vehicle, fuel-production and infrastructure investments of very large proportions. Hydrogen infrastructure should remain an important candidate for future support under the California Alternative Fuels Infrastructure Program.

5.6 Recommendations for AFV Infrastructure Incentives

An important ongoing need in advancing the commercial viability of clean fuel technologies is to implement effective, affordable and workable incentives. Until economies of scale can be realized to make alternative fuel technologies self sustaining, manufacturers and consumers need assistance in offsetting higher costs and/or reduced utility compared to conventional vehicles.

Many types of incentives have been used in California and other states to support AFV deployment, but some have clearly been more effective than others. Generally, state and local grants have provided the best motivation for fleets to purchase AFVs, whereas tax credits have worked well for individual AFV owners. In some cases, well-meaning but poorly designed and implemented incentive programs have resulted in ineffective use of funds. Greater understanding is needed on the mechanics of effective incentives for AFVs and fueling stations. It is recommended that the Energy Commission and its partners conduct a detailed assessment of financial and administrative incentives that can most effectively help deploy AFVs with maximum displacement of petroleum fuels. This assessment will need to take into account rapidly evolving landscapes for regulations and fiscal issues that affect incentive programs.

6. Appendix: Air Quality Regulations and Petroleum Displacement

6.1 Light-Duty Vehicles

In California, LDVs have been subject to the world's most stringent emission standards since the late 1960s. In recent years especially, major strides have been achieved in reducing emissions from conventionally fueled LDVs, directly as a result of the CARB's landmark Low-Emission Vehicle regulations adopted in 1990, as well as "competition" from low-emitting vehicles deployed under various Energy Commission AFV program. Gasoline-powered "Partial Zero Emission Vehicles (PZEVs), are now available at comparable prices to conventional LDVs (see Table 34). PZEVs meet the very stringent Super Ultra Low Emission Vehicle (SULEV) standard (i.e., they emit about 90 percent less ozone-precursor emissions compared to the average new 2003 automobile), while meeting additional stringent requirements. The Honda Civic GX, an AFV that uses a "dedicated" natural gas engine, has also been certified to the PZEV standard.

Table 34.
2003 LDV types certified to CARB's most stringent emission standards

	No. of MY 2003 Passenger Car Engine Families Certified in California to Standard		
Technology Type / Fuel	**ZEV or PZEV***	**SULEV****	**ULEV*****
Internal Combustion Engine / Gasoline	7 (PZEV)	1	35
Internal Combustion Engine / Compressed Natural Gas	1 [a]	0	0
Hybrid-Electric / Gasoline	0	3[b]	2[b]
Battery Electric / Grid Electricity	0	0	0
Fuel Cell Electric / Methanol or Hydrogen	0	0	0

Source: CARB website, April 2003. Additional certifications may have occurred that were not yet posted on the website.

*PZEV = Partial Zero-Emission Vehicle, **SULEV = Super-Low Emission Vehicle, ***ULEV = Ultra-Low Emission Vehicle

[a]Honda Civic GX

[b]Commercially available SULEV hybrid-electric vehicles (hybrids) are the Toyota Prius, the Honda Insight, and the Honda Civic hybrid. Versions of the two Honda hybrids are also available in ULEV configurations.

With progressively cleaner cars becoming commercially available, operators of LDV fleets can achieve significant emission reductions in their fleet simply through the practice of replacing older vehicles with progressively lower-emitting vehicles fueled by gasoline. As long as advanced-technology gasoline LDVs can meet the most stringent standards at little or no incremental vehicle and infrastructure costs – and gasoline remains affordable and abundantly available – air quality may not be a driving force to deploy significant numbers of light-duty AFVs in California over the next five years.[226] However, the use of clean fuels in certain light-duty applications can still offer compelling benefits towards sustainable use of alternative fuels in California, directly resulting in displacement of petroleum fuels.

6.2 Medium-Duty Vehicles

As Table 35 shows, two engine families in the medium-duty sector have been certified to SULEV standards. Both of these engine families, Chrysler's 5.2 liter CNG engine and Ford's 5.4 liter CNG engine, are fueled by natural gas.[227] SULEVs in this category are 70 percent lower emitting than average new vehicles of similar weight, according to CARB (details about these categories can be found at CARB's "Buyer's Guide to Cleaner Cars" at http://www.arb.ca.gov/msprog/). To date, 15 medium-duty engine families (from a wide variety of manufacturers) have been certified to the ULEV standard for the 2003 model year. Of these, only the 4.3 liter Baytech CNG engine is an alternative fuel configuration. ULEV-certified MDVs are 50 percent cleaner than the average new vehicle of similar weight.

Table 35.
2003 MY medium-duty vehicle certifications by type

	No. of MY 2003 MDV Engine Families Certified in California to Standard		
Technology Type / Fuel	**ZEV***	**SULEV****	**ULEV*****
Internal Combustion Engine / Gasoline	0	0	15
Internal Combustion Engine / Compressed Natural Gas	0	2	1
Hybrid-Electric / Gasoline	0	0	0
Battery Electric / Grid Electricity	0	0	0
Fuel Cell Electric / Methanol or Hydrogen	0	0	0

*ZEV = Zero-Emission Vehicle (2000 Model Year)
**SULEV = Super-Low Emission Vehicle
***ULEV = Ultra-Low Emission Vehicle

It is notable that the lowest-emitting vehicles in medium-duty applications continue to be alternative fueled. Use of such vehicles instead of currently available gasoline-fueled MDVs can simultaneously displace gasoline consumption and provide air quality benefits. However, the emission-competitiveness of gasoline-fueled MDVs continues to improve. As this happens, the focus on benefits of medium-duty AFVs will transition to the petroleum-displacement side of the equation.

6.3 Heavy-Duty Vehicles

In the heavy-duty vehicle (HDV) sector, the use of alternative fuels can displace large volumes of petroleum fuel while also delivering clear and compelling emission benefits, at least in the near term. There are approximately 750,000 HDVs registered in California.[228] Including out-of-state vehicles, more than 1.25 million heavy-duty diesel trucks, buses and off-road vehicles are operated throughout California.[229] Many of these engines are equipped with little or no emission control technology. On-road HDVs alone contribute nearly 40 percent of all NO_x emissions from mobile sources in California. NO_x is a major ingredient in the formation of ozone, the main harmful component of urban smog. Fine particulate matter exhaust from heavy-duty diesel engines contributes to mortality, and CARB has identified it as a toxic air contaminant.[230]

Today there are numerous alternative-fuel heavy-duty engines that have demonstrated superior emission performance compared to currently available diesel engines. As of April 2003, there are still no diesel-fueled engines certified to CARB's Optional NO_x Emission Credit Standards (2.5 grams per brake horsepower-hour, or lower) for HDVs. By contrast, since the 1998 model year dozens of heavy-duty alternative fuel engines meeting these standards have been offered for sale in California. For the 2003 model year, three different manufacturers have certified heavy-duty engines on natural gas that meet optional certification standards of 1.8 grams per brake horsepower-hour (NO_x + non-methane hydrocarbon), or lower.

Largely based on the proven emission-reduction potential of various alternative fuel HDVs using these engines, California agencies have adopted regulatory drivers and/or incentives to assist deployment of these vehicles. For example, CARB's Public Transit Bus Fleet Rule was specifically designed to increase the deployments of low-emission alternative-fuel engines, including advanced battery and fuel cell technology use.[231] This regulation affects about 8,500 transit buses at 75 different transit districts. As originally adopted, the rule required transit agencies to select one of two "paths" to compliance. For the alternative fuel path, it stipulated that 85 percent or more of all new bus purchases must be alternative fuel through the 2015 model year.[232] For transit agencies choosing the diesel path, it required obtaining equivalent fleet-averaged emission reductions by 2010. Larger transit districts (>200 buses) on the diesel path also were required to conduct demonstrations of Zero-Emission Buses (ZEBs) in 2003 and begin purchasing ZEBs in 2008 -- two years before transit districts on the alternative fuel path.

Initially, 53 percent of California's transit districts opted for the diesel path, and 35 percent opted for the alternative fuel path, with 12 percent undecided.[233] In late 2002, ARB staff proposed to modify the statewide transit bus fleet rule to provide greater flexibility in meeting the requirements, while attempting to encourage greater deployment of advanced technologies such as hybrid electric buses. Although the California's transit bus fleet rule may be significantly modified, it is likely to still be a significant driver for continued deployment of alternative fuel technologies, as well as advanced technologies such as fuel cells over the longer term.

California's air pollution control districts are also adopting major drivers for HDVs using alternative fuels. The SCAQMD has adopted a series of "fleet rules" for end users in the South Coast Air Basin (SCAB) that effectively require a phasing out of current-technology diesel vehicles in favor or heavy-duty AFVs, or their emission equivalent. Table 36 lists SCAQMD's adopted or proposed fleet rules affecting HDVs, and the estimated populations for potential conversion to alternative fuels.

Table 36.
SCAQMD's adopted or proposed fleet rules affecting HDVs

SCAQMD Fleet Rule No.	Targeted Fleet Type(s)	Estimated SCAB HDV Population for Potential Conversion to Alt. Fuels[234]
1192	Transit Buses	5,000
1193	Refuse Haulers	6,000
1194	Airport Support Vehicles	500
1186.1	Street Sweepers	700
1196	Heavy-Duty Public Fleets	4,100
Total		**16,300**

Sources: SCAQMD staff reports on fleet rules, and personal communication from David Coel of SCAQMD, to Jon Leonard of TIAX, on 3/27/01

However, as regulators acknowledge in these rules, the emission competitiveness of diesel-fueled HDVs will rapidly improve over the next decade. The major drivers are a series of progressively more stringent new heavy-duty engine emission standards, coupled with requirements for cleaner diesel fuel, promulgated by CARB and EPA. In late 2000, CARB approved a comprehensive Diesel Risk Reduction Plan that includes 14 measures to reduce emissions from both new and existing diesel-fueled engines and vehicles. Among these measures are the establishment of more stringent emission standards that will take effect in 2002 and 2004. In early 2001, EPA also adopted more stringent emission requirements for heavy-duty diesel engines. As part of this program, new emission standards will take effect in model year 2007 and will apply to HD highway engines and vehicles. To meet these standards with diesel engines, it is expected that manufacturers will need to incorporate advanced diesel emission control technologies such as catalyzed diesel particulate filters and NO_x adsorbers. Because sulfur renders these systems ineffective, both CARB and EPA are requiring sulfur levels in highway diesel fuel to be reduced more than 90 percent by 2006.[235,236]

As a result, there is less certainty about the emission advantages of alternative fuels as these new and more stringent emission standards take full effect. Heavy-duty engine manufacturers have indicated that advanced diesel engine technologies combined with low-sulfur diesel fuel will be able to duplicate or better the emission performance of today's alternative fuel engines. Meanwhile, several manufacturers are also involved in efforts to further reduce emissions from their natural gas engines, to NO_x levels about 75 percent lower than today's natural gas engines.[237]

Looking out past 2004, air-quality drivers for alternatively alternatively-fueled HDVs become even less concrete. By 2007, both diesel and alternative-fuel heavy-duty engines will need to emit about 90 percent less NO_x and PM than today's lowest-emitting alternative fuel engines. These fuel-neutral standards will be challenging for both advanced diesel and alternative fuel engines. However, it is noteworthy that diesel engines have significantly "farther to go" in reaching the target levels. Taking an alternative fuel approach may offer significant engineering and cost advantages, at least for certain engines and applications.

ENDNOTES

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[1] Some charging locations could have multiple types of chargers and multiple charging stations.

[2] California Energy Commission's Transportation Fuels Office, April 2003 Department of Motor Vehicles data base search results.

[3] California Energy Commission, various documents from website (http://www.energy.ca.gov/).

[4] Patrick Keilch, City of Berkeley Deputy Director of Public Works, email communication to Peter Ward and others of California Energy Commission, June 19, 2003.

[5] For example, Energy Commission staff have made preliminary estimates about the costs of modifying an existing diesel terminal for Fischer-Tropsch diesel.

[6] California Energy Commission, California Air Resources Board, and California Department of General Services, "California State Vehicle Fleet Fuel Efficiency Report: Volume I Summary of Findings and Recommendations," Commission Report P600-03-003, May 2003.

[7] California Air Resources Board, Staff Report: Initial Statement of Reasons – Proposed Regulation for a Public Transit Bus Fleet Rule and Emission Standards for New Urban Buses, January 27, 2000.

[8] In fact, Sunline Transit Agency is joining with Cummins Westport to test special buses fueled by a mix of 93% CNG and 7% compressed hydrogen (by energy content). The hydrogen component of the fuel helps to reduce NOx emissions further, compared to 100% CNG fuel.

[9] Some heavy-duty natural gas engines use pilot injection of diesel fuel to assist with compression ignition of the natural gas fuel – these technologies are technically "dual fuel" but cannot be operated in a diesel-only mode, and are increasingly being viewed as "dedicated."

[10] Many dedicated, optimized NGVs and natural gas engines *currently* offer significant emissions benefits and help reduce petroleum dependency.

[11] In April 2003, the Energy Policy Act 2003 was passed by the U.S. Senate Energy & Natural Resources Committee, and was moving to the full Senate as of early May 2003. The extent (if any) to which the new proposed version of EPACT will require actual use of alternative fuels is unclear.

[12] According to the United States General Accounting Office, February 2000.

[13] This refers to all CNG and liquefied natural gas (LNG) stations, excluding home-appliance sized CNG units.

[14] However, this table also shows that in certain applications (e.g., taxicabs), LDVs and MDVs can consume large amounts of fuel.

[15] GGE = gasoline gallon equivalent and DGE = diesel gallon equivalent (referring to energy content)

[16] Natural Gas Vehicle Coalition, "NGVC Analysis of Transit Bus Market: Executive Summary," based on APTA data as of December 31, 2001.

[17] Arthur D. Little – Acurex Environmental (now TIAX), Liquefied Natural Gas for Heavy-Duty Transportation, Final Report, May 15, 2001, prepared for Gas Technology Institute and DOE / Brookhaven National Laboratories, downloaded from http://www.trucks.doe.gov/pdfs/F/128.pdf.

[18] California Energy Commission, California LNG Transportation Fuel Supply and Demand Assessment, Consultant Report P600-02-002F, January 2002, prepared by USA Pro & Associates and St. Croix Research.

[19] American Public Transportation Association, "Standard Bus Procurement Guidelines – Low-Floor CNG," July 3, 2001, online at http://spider.apta.com/lgwf/procure/lfcngtxt.doc.

[20] For example, in some demonstrations of Class 8 LNG trucks, their reduced range (about 25%) relative to diesel trucks has restricted use to local deliveries, while diesel control vehicles are used to make interstate deliveries with much higher monthly mileage accumulation. Also, reduced range of CNG buses versus diesel buses has been a significant issue with some transit districts.

[21] "Acceptable" range varies by fleet, application and other factors. For typical medium-duty applications, as a rule of thumb at least a 180-mile range is needed to operate the average vehicle with full utility.

[22] E-mail from Edward J. Lyford-Pike,Chief Engineer, Advanced Engineering, Alternative Fuels, Cummins Engine Company, to Jon Leonard of TIAX, December 2000.

[23] Storage vessels using advanced materials are being designed for pressures up to 5,000 psi and higher, by companies such as Quantum. These tanks can offer significant volumetric and gravimetric improvements in energy storage, although cost may be an issue.

[24] Mike Eaves, Executive Director, California NGV Coalition, input to the California Energy Commission on the Clean Fuels Market Assessment, March 5, 2003

[25] Budgets and future available incentives for some of these programs are currently in doubt do to State budget shortfalls.

[26] California Air Resources Board, "Urban Transit Bus Fleet Rule," PDF from website http://www.arb.ca.gov/msprog/bus/fuelpathslctn.pdf.

[27] CARB data indicate that 11 of the larger transit districts in the South Coast Air Basin declared the alternative fuel path, while seven of the small- to medium-sized transit districts declared the diesel path. CARB is considering amendments to the bus fleet rule to address how to obtain a higher rate of compliance through the alternative fuel path.

[28] In April 2003, the Energy Policy Act 2003 was passed by the U.S. Senate Energy & Natural Resources Committee, and was moving to the full Senate as of early May 2003. The extent (if any) to which the new proposed version of EPACT will require actual use of alternative fuels is unclear.

[29] Mike Eaves, Executive Director, California NGV Coalition, input to the California Energy Commission on the Clean Fuels Market Assessment, March 5, 2003.

[30] Source: Website of the National Alternative Fuel Training Consortium (http://naftp.nrcce.wvu.edu/).

[31] California Energy Commission, Volume II of draft consultant's report on State fleet fuel efficiency (SB 1170), prepared by TIAX, January 2003.

[32] California Energy Commission, Volume II of draft consultant's report on State fleet fuel efficiency (SB 1170), prepared by TIAX, January 2003.

[33] Details about these propane stations are described in California Alternative Fuels Infrastructure Program Evaluation, a draft Consultant's Report by TIAX for the California Energy Commission.

[34] According to the California Air Resources Board website, as of May 2003.

[35] Steve Moore, Mutual Propane, memorandum to Jim Folkman of the Energy Commission, March 17, 2003.

[36] California Air Resources Board and U.S. Environmental Protection Agency recently certified the B LPG Plus to 2004 2.5 g/bhp-hr NOx plus NMHC.

[37] Western Propane Gas Association, A Few Reasons Why Propane is the Leading Clean Air Vehicle Fuel, supplement to "Technical Resource Guide" handed out by the San Diego Regional Clean Fuel Coalition at the 2000 Clean Cities national meeting.

[38] National Renewable Energy Laboratory, Alternative Fuels Data Center, PDF entitled "Model Year 2002 Alternative Fuel Vehicles," website at www.afdc.doe.gov/.

[39] According to input received from the propane industry members of the Technical Advisory Group, March 2003.

[40] While CARB has already certified Capstone's microturbine fueled by LPG, CNG and diesel for use in commercial hybrids (e.g, those demonstrated at LADOT), no additional information is available about commercialization plans.

[41] Jim Ortner, OCTA, personal communication to Jon Leonard, April 4, 2001.

[42] CARB recognized that other zero-emission technologies might eventually emerge, such as direct-hydrogen fuel cell vehicles, to enable automakers to meet their ZEV obligations. However, "ZEV" and "battery EV" have been essentially synonymous in the early years of the program.

[43] California Air Resources Board, "2003 ZEV Program Rulemaking," March 25, 2003, from website (http://www.arb.ca.gov/msprog/zevprog).

[44] However, automakers will be able to receive credit for qualifying vehicles (e.g., ZEVs) that they choose to sell or lease in 2003-04.

[45] California Air Resources Board, "ARB Modifies Zero Emission Vehicle Regulation," Press Release 03-11, April 24, 2003, from website (http://www.arb.ca.gov/newsrel/nr042403.htm).

[46] Electric Power Research Institute, "Comparing the Benefits and Impacts of Hybrid Electric Vehicle Options," July, 2001, (EPRI Report 1000349).

[47] "Kansas City to Test Plug-In Hybrid Bus," EV World, citing KMPC Channel 9 report from June 10, 2003, downloaded on August 8, 2003 from http://www.evworld.com/.

[48] While these EVs were reportedly available in 2000 (with the exception of the Honda EV PLUS), many interested customers claimed that they were unable to actually obtain vehicles.

[49] California Air Resources Board, About EVs, http://www.zevinfo.com, information "as of March 2000."

[50] CARB, "2003 ZEV Program Rulemaking," March 25, 2003.

[51] Nissan reportedly offers lease of its Altra EV and a neighborhood electric vehicle (NEV), but only to "select commercial fleets" in California.

[52] General Motors Corporation, letter from Ken Stewart, Brand Manager, to EV_1 lessees, February 7, 2002.

[53] Toyota Motor Corporation, online (http://www.toyota.com/html/shop/vehicles/ravev/rav4ev_0_home/index.html) as of May 2003.
[54] Southern California Edison, "Performance Characterization: 1999 Nissan Altra with Lithium-Ion Battery," September 1999.

[55] Nissan USA Motors, information about Altra EV on website, www.nissanusa.com, as of May 2003.

[56] Kurani, Kenneth. T. Turrentine and D. Sperling (U.C. Davis), "Testing Electric Vehicle Demand in 'Hybrid Households' Using a Reflexive Survey," Transportation Research D. Vol 1, No. 2, 1996. Also see: Green Car Institute, "The Current and Future Market for Electric Vehicles," September, 2000.

[57] David Modisette, Executive Director of the California Electric Vehicle Transportation Coalition, input provided to the California Energy Commission on draft Clean Fuels Market Assessment 2003, August 2003.

[58] Menahem Anderman, Fritz R. Kalhammer and Donal MacArthur, Advanced Batteries for Electric Vehicles: An Assessment of Performance, Cost, and Availability, Prepared for the California Air Resources Board, June 2000.

[59] David Modisette, Executive Director of the California Electric Vehicle Transportation Coalition, August 2003.

[60] "Honda, Toyota Officials Report Increase in HYBRID Sales," Electric Vehicle Today, April 02, 2003.

[61] CARB, "2003 ZEV Program Rulemaking," March 25, 2003.

[62] Essentially the same engine technology is used in FFVs that operate on an 85% methanol / 15% gasoline blend (M85).

[63] National Renewable Energy Laboratory, Alternative Fuels Data Center website (http://www.afdc.nrel.gov/altfuel/eth_general.html).

[64] California Energy Commission's Transportation Fuels Office, April 2003 Department of Motor Vehicles data base search results.

[65] The leading fuel cell technology for automotive propulsion is the Proton Exchange Membrane Fuel Cell, to which this document refers.

[66] California Air Resources Board, "ARB Modifies Zero Emission Vehicle Regulation," Press Release 03-11, April 24, 2003, from website (http://www.arb.ca.gov/newsrel/nr042403.htm).

[67] According to the California Energy Commission, http://www.energy.ca.gov/afvs/m85/index.html.

[68] On-board reforming increases costs, lowers vehicle efficiency and results in tailpipe emissions (albeit, at very low levels).

[69] For example, Ballard Power Systems has supplied automotive fuel cells to DaimlerChrysler, Ford, Daewoo, General Motors, Honda, Hyundai, Mazda, Nissan, Volkswagen, and Volvo (per Ballard website, www.ballard.com).

[70] Alan C. Lloyd, California Air Resources Board Chairman and 2003 Chair of the California Fuel Cell Partnership. *Testimony submitted to the Committee on Science of the U.S. House of Representatives*, March 5, 2003.

[71] SunLine Transit Agency website (www.sunline.org)

[72] AC Transit website (www.ACTransit.org).

[73] For example, TIAX LLC and UC-Davis have been working with the National Renewable Energy Laboratory to assess the infrastructure needs of transit districts that will demonstrate a few hydrogen-fueled demonstration buses in 2003, and begin purchasing them in 2008.

[74] International Academy of Science, Hydrogen Tech Paper #89001, "Hydrogen Fuel Cell Vehicles, " 1997, by Dr. Roger E. Billings.

[75] U.S. Department of Energy, Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan, draft report, June 3, 2003, online at http://www.eere.energy.gov/hydrogenandfuelcells/mypp/.

[76] International Academy of Science, Hydrogen Tech Paper #89001, "Hydrogen Fuel Cell Vehicles, " 1997, by Dr. Roger E. Billings.

[77] According to the U.S. DOE (www.fueleconomy.gov), the 2003 Honda Accord is the most-fuel-efficient conventional ICE sedan in its class (29 mpg, combined city / highway). Assuming a 15% loss of mpg in real-world driving, and given the Accord's 17.1 gallon fuel tank, its driving range would be about 420 miles.

[78] U.S. Department of Energy, Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan, draft report.

[79] Ibid.

[80] Challenges include cost and supply issues for precious metals and other materials making up membrane-electrode assemblies; the need for advanced, lower-cost hydrogen storage technology; tradeoffs associated with on-board air compression versus using ambient pressure stacks; and difficulties with delivery of constant power during transient operation.

[81] Ballard Power Systems, website (www.ballard.com) as of May 8, 2003.

[82] This assumes that there are 5 large transit districts (>200 buses), and each will need to procure an average of 8 buses per year, 15% of which will need to be ZEBs.

[83] Ballard Power Systems and Daimler Chrysler, joint press release, May 5, 2003.

[84] WestStart-CALSTART, *"Delphi" Market Forecast Exercise: Results and Analysis Clean Heavy Duty Vehicles Conference 2003*, online at http://www.weststart.org/programs/chdvc/delphiservey_files/delphi.pdf.

[85] U.S. Department of Energy, Energy Information Administration, "Table 2: Natural Gas Production, Transmission and Consumption by State, 2001, from website (www.EIA.DOE.gov), as of May 8, 2003.

[86] California Department of Conservation: Division of Oil, Gas, and Geothermal Resources, 2000 Preliminary Report of California oil and Gas Production Statistics, January 2001, from website (http://www.consrv.ca.gov/dog/publications/whatsup.htm).

[87] Estimates for California's consumption may differ depending on the source – this estimate is from the Energy Information Administration, but California Energy Commission estimates may be lower.

[88] California Energy Commission website (www.energy.ca.gov.gov/naturalgas) and Energy Information Administration website (www.eia.doe.gov/oil_gas/natural_gas/nat_frame.html).

[89] California Energy Commission, "California Natural Gas Analysis and Issues," Staff Report P200-00-006, November 2000, from website (http://www.energy.ca.gov/naturalgas).

[90] California Energy Commission, "Natural Gas Pipeline and Storage Projects: Infrastructure Projects Completed Since 2001," April 11, 2003, from website (http://www.energy.ca.gov/naturalgas/index.html)

[91] California Energy Commission, "Natural Gas Pipeline and Storage Projects: Pending Infrastructure Projects," April 11, 2003, from website (http://www.energy.ca.gov/naturalgas/index.html)

[92] Statement of Mark J. Mazur, Acting Administrator, Energy Information Administration, before the Committee on Commerce, Subcommittee on Energy and Power, U.S. House of Representatives, September 28, 2000.

[93] California Energy Commission, "Natural Gas Price Increases – Frequently Asked Questions," website (http://www.energy.ca.gov/naturalgas/natural_gas_faq.html), as of December 10, 2000.

[94] Applications to build new California pipeline capacity have been stepped up in recent months, and the US Federal Energy Regulatory Commission has pledged that it will act "as quickly as possible" to expedite approval of new pipelines (Oil & Gas Journal, March 2, 2001).

[95] California Energy Commission, "Natural Gas Market Prices, Executive Summary," website http://www.energy.ca.gov/2003_price_spikes/natural_gas_exec_sum.html, as of April 29, 2003.

[96] California Energy Commission, "Weekly Natural Gas Prices," website (http://www.energy.ca.gov/naturalgas/update.html), as of May 11, 2003.

[97] Source: California Air Resources Board, press release from website (http://www.arb.ca.gov/energy/energy.htm).

[98] Governor Gray Davis, Press Release: "Approved Power Plants Will Add Over 2,000 Megawatts," March 22, 2001.

[99] California Energy Commission, "Natural Gas Market Prices, Executive Summary," as of April 29, 2003.

[100] California Energy Commission, "Causes for Increases in Gasoline & Diesel Prices in California: Executive Summary," from http://www.energy.ca.gov/2003_price_spikes/gasoline_exec_sum.html

[101] 34 TCF for 2020 is the mid estimate provided by the Energy Information Administration, Annual Energy Outlook 2001, Report #DOE/EIA-0383(2001), December 22, 2000, from EIA website (http://www.eia.doe.gov).

[102] California Energy Commission, "Natural Gas Supply and Infrastructure Assessment," Staff Paper 700-02-006F, December 2002, from website (http://www.energy.ca.gov/reports).

[103] California Energy Commission, "Natural Gas Supply and Infrastructure Assessment," Staff Paper 700-02-006F.

[104] Energy Information Administration, "Annual Energy Outlook 2003," Report #DOE/EIA-0383(2003), January 2003, from EIA website (http://www.eia.doe.gov).

[105] A vehicle with a gross vehicle weight (GVW) of 33,001 lbs. up to 80,000 lbs.

[106] For a description and additional information on the TAG please see section 2.3 "Technical Advisory Group"

[107] Jan Hull, Trillium USA, input to the California Energy Commission on the draft Clean Fuels Market Assessment 2003, email dated August 2003.

[108] Fred Minassian, Technology Implementation Manager, SCAQMD, "importance of Infrastructure to the California NGV Partnership," presentation at the Southern California AFV Expo & Natural Gas Infrastructure Workshop, December 4, 2003.

[109] Personal communication from the Escondido Shell station manager to Jon Leonard, August 4, 2000. Corroborated by the California Natural Gas Vehicle Coalition website at http:\\www.califngv.org.

[110] Arthur D. Little staff called all three stations on August 4, 2000 and again on March 6, 2001. Each was still selling CNG.

[111] According to www.CleanCarMaps.com, as of May 13, 2003.

[112] Trillium USA, "Comments on the 2001 Clean Fuels Market Assessment," submitted to the California Energy Commission in March 2003, undated.

[113] Commodity Cost = (Pump Price - Compression Costs - Transport Costs - Taxes/Fees)

[114] CNG prices were provided to Jon Leonard of TIAX by staff of the SoCalGas LEV Program on May 13, 2003.

[115] James Harger, Senior Vice President, ENRG, presentation at the Southern California AFV Exposition & Infrastructure Workshop, December 4, 2003.

[116] Note: these stations vary widely in size, type (fast vs. slow fill, etc.) and intended use.

[117] Fred Minassian, "importance of Infrastructure to the California NGV Partnership," presentation at the Southern California AFV Expo & Natural Gas Infrastructure Workshop, December 4, 2003.

[118] Based on private communications with Jan Hull of Trillium USA, and TIAX's ongoing work to assess the costs of CNG infrastructure.

[119] ENRG, press release of February 6, 2003, from website (www.cleanenergyfuels.com), as of May 13, 2003.

[120] California Natural Gas Vehicle Coalition website, *Fueling Stations Directory*.

[121] For example, ENRG has joined with Multiforce Systems Corporation to deploy "Beta" CNG stations in Southern California with Multifore's FuelForce automated fuel management system, which can accept VISA and Mastercard. A partnership between U.S. Bank Voyager and Multiforce integrates in the Voyager Universal Fleet Credit Card program.

[122] In April 2003, the Energy Policy Act 2003 was passed by the U.S. Senate Energy & Natural Resources Committee, and was moving to the full Senate as of early May 2003. The extent (if any) to which the new proposed version of EPACT will require actual use of alternative fuels is unclear.

[123] Mike Eaves, Executive Director, California NGV Coalition, input to the California Energy Commission on the Clean Fuels Market Assessment, March 5, 2003.

[124] As previously noted, Sunline Transit Agency and Cummins Westport are testing special buses fueled by a mix of 93% CNG and 7% compressed hydrogen (by energy content). The hydrogen component of the fuel helps to reduce NOx emissions further, compared to 100% CNG fuel

[125] Richard Cromwell, General Manager/CEO of Sunline Transit Agency, TAG input to Peter Ward of the Energy Commission on the Clean Fuels Market Assessment update, October 9, 2002.

[126] In particular, DOE and SCAQMD have invested very significant funding and staff time to support FuelMaker's HRA concept. The California NGV Partnership, which includes both agencies, projects "major growth" for the home refueling option.

[127] SCAQMD, Board Agenda No. 3, February 16, 2001.

[128] California Energy Commission, California LNG Transportation Fuel Supply and Demand Assessment, Consultant Report P600-02-002F, January 2002, prepared by USA Pro & Associates and St. Croix Research.

[129] Fleets normally buy fuel before taxes, and then pay all applicable taxes to various agencies. Fuel taxes for LNG vary by fleet type. The maximum federal excise tax paid for LNG is 11.9 cents per LNG gallon. The State excise tax allows payment of a flat annual fee of $168 per vehicle per year – this is advantageous to high-fuel-use fleets.

[130] From survey input by Erik Neandross of Gladstein & Associates, October 2000.

[131] Jim Ortner, Orange County Transit Authority, personal communication to Jon Leonard, 4/3/01.

[132] Some LNG vendors that were formally setting fixed contract prices over long term are now setting moving prices according to monthly indices.

[133] Personal communication from Jim Ortner, OCTA, to Jon Leonard of TIAX, February 26, 2003.

[134] Personal communication from TAG member Erik Neandross (Gladstein & Associates) to Jon Leonard of TIAX, May 14, 2003.

[135] Orange County Transit Authority invested about $4.5 million in total for its two existing LNG stations, which currently fuel 232 LNG buses.

[136] Survey received from Jim Harger, Vice President of Marketing, Pickens Fuel Corporation, December 6, 2000.

[137] E-mail from Gary Pope, USA PRO, to Jon Leonard of TIAX, December 12, 2000.

[138] This paragraph is based on direct input provided in mid 2001 to the Energy Commission from a member of the TAG that supplies LNG to many California HDV fleets.

[139] Arthur D. Little – Acurex Environmental (now TIAX), Liquefied Natural Gas for Heavy-Duty Transportation, Final Report, May 15, 2001, prepared for Gas Technology Institute and DOE / Brookhaven National Laboratories, downloaded from http://www.trucks.doe.gov/pdfs/F/128.pdf.

[140] At least one plant in California, as well as several plants in nearby western states, produce LNG in significant quantities – but to date these have not been a source of LNG for the California transportation fuel market.

[141] California Energy Commission, California LNG Transportation Fuel Supply and Demand Assessment, Consultant Report P600-02-002F, January 2002, prepared by USA Pro & Associates and St. Croix Research.

[142] Ibid.

[143] For example, the Energy Commission, U.S. DOE and SCAQMD plan to cost share a demonstration project utilizing compost and digester gases for the operation of a low Btu microturbine for electricity generation

[144] California Energy Commission, Economic and Financial Aspects of Development in California, Consultant Report 500-02-020F, April 2002, online (http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF).

[145] California Energy Commission, Economic and Financial Aspects of Development in California, Consultant Report 500-02-020F, April 2002, online (http://www.energy.ca.gov/reports/2002-04-08_500-02-020F.PDF).

[146] For example, the Energy Commission, U.S. DOE and SCAQMD plan to cost share a demonstration project utilizing compost and digester gases for the operation of a low Btu microturbine for electricity generation

[147] California Energy Commission, Renewable Energy Program: Quarterly Report to the Legislature, January 2003 to March 2003, from website (http://www.energy.ca.gov/reports/2003-05-02_500-03-022V1.PDF).

[148] City of San Diego, "Clean Energy Initiatives," from website (www.sanmet.gov/environmental-services) as of May 10, 2003.

[149] Bruce Wilding, Idaho National Engineering Laboratory, "Sacramento Small Scale Liquefier Plant," presentation to NGVTF Technical Committee, January 28-29, 2003.

[150] Mike Eaves, Executive Director, California NGV Coalition, input to the California Energy Commission on the Clean Fuels Market Assessment, March 5, 2003

[151] U.S. EPA, "Clean Alternative Fuels: Fischer-Tropsch," March 2002, online (http://www.epa.gov/otaq/consumer/fuels/altfuels/fischer.pdf)

[152] Different CNG compression strategies have a significant effect on gas temperature, and therefore fill completeness. Some CNG providers (e.g., Pinnacle CNG) are improving CNG fills using advanced temperature compensation, and other technologies.

[153] Transportation Research Board, *TCRP Report 38: Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Operations.*

[154] This information is based on TIAX's experience preparing L/CNG station RFPs, and input provided by 1) Steve Bartlett of ALT USA and 2) Chart Applied Technologies.

[155] Information provided by Mr. Steve Moore of Mutual Liquid Gas.

[156] For example, LPG stations have no maintenance associated with gas compression and drying.

[157] Western Propane Gas Association, written communication to the California Energy Commission, undated (circa March 2003), provided to TIAX on April 23, 2003.

[158] Estimates range from 33% to 50% for the amount of California's propane supply that is obtained as a by-product from natural gas processing.

[159] Western Propane Gas Association to the California Energy Commission, undated (circa March 2003).

[160] California Energy Commission, California Air Resources Board, and California Department of General Services, California State Vehicle Fleet Fuel Efficiency Report: Volume 1 Summary of Findings and Recommendations, Commission Report P600-03-003, May 2003, online (http://www.energy.ca.gov/reports/2003-05-01_600-03-003-VOL1.PDF).

[161] Source: Website of the National Alternative Fuel Training Consortium (http://naftp.nrcce.wvu.edu/).

[162] The basic source of information from this section is from the websites of the National Propane Gas Association (www.npga.com) and the National Propane Council (www.propanecouncil.org). The source of most cost and price information is the Department of Energy's Energy Information Association (www.eia.doe.gov)

[163] National Propane Gas Association website (www.npga.com).

[164] National Propane Gas Association, press release, March 5, 2003, from website (http://www.npga.org).

[165] Delta Liquid Energy, information provided to TIAX by employees at four different locations dispensing propane as a motor vehicle fuel, May 20, 2003.

[166] Robert Jacobs, Delta Liquid Energy, personal communication to Jon Leonard of TIAX, May 20, 2003.

[167] Delta Liquid Energy, information provided to TIAX by employee at the Paso Robles fueling station, May 20, 2003

[168] Personal communication, Bill Platz, Delta Liquid Energy, to Jon Leonard, April 2, 2001.

[169] Based on spreadsheets provided to TIAX in March 2003 by Energy Commission staff, summarizing recent expenditures for clean fuels infrastructure.

[170] Survey input received from Bill platz, Delta Liquid Energy Company.

[171] Source: Website of the National Alternative Fuel Training Consortium (http://naftp.nrcce.wvu.edu/).

[172] Survey input from the California Electric Vehicle Coalition, December 2000.

[173] Survey input indicated that discussions have occurred about a North-South corridor for EV charging in California, but no concrete plans have yet been made.

[174] NGVs can also be refueled (slow-filled) at home with FuelMaker systems, and some NGV manufacturers have set up incentives for their use (e.g., Honda sales of its Civic GX). FuelMaker will reportedly launch a commercial home refueling device called "Phill" in 2004.

[175] Arthur D. Little, Inc, "Report on the Electric Vehicle Markets, Education, RD&D and the California Utilities LEV Programs", March 22, 2002, Final Report FR-02-109.

[176] California Energy Commission, "2002 – 2012 Electricity Report," Commission Final Report P700-01-004F, February 2002.

[177] Ibid.

[178] California Air Resources Board, ZEV Infrastructure: A Report on Infrastructure for Zero-Emission Vehicles, January 2001.

[179] According to survey input from CalETC.

[180] According to survey input from CalETC.

[181] Survey input from CalETC and the Clean FuelConnection, Inc.

[182] General Motors Corporation, letter from Ken Stewart, Brand Manager, to EV_1 lessees, February 7, 2002.

[183] National Ethanol Vehicle Coalition, Press Release, February 13, 2003. "NEVC Awards E85 Infrastructure Money to California Department of Food and Agriculture and InterState Oil Company."

[184] Energy Information Administration, Energy Outlook 2001, December 22, 2000.

[185] Presumably, all this E85 would be used to fuel FFVs, since there are currently no other mainstream uses for E85, and E-100 will be needed if ethanol is to be used in fuel cell vehicles.

[186] California Energy Commission, "California's Phaseout of MTBE – Background and Current Status," presentation by Gordon Schremp, March 17, 2003.

[187] California Energy Commission, press release, Report Says California Can Benefit from Biomass-Based Ethanol Industry, March 21, 2001.

[188] California Energy Commission, "California's Phaseout of MTBE – Background and Current Status."

[189] William J. Keese, Chairman, California Energy Commission, "Causes for Gasoline and Diesel Price Increases in California," March 28, 2003, from website (http://www.energy.ca.gov/2003_price_spikes/2003-04-02_GASOLINE_FINAL.PDF),

[190] California Energy Commission, Costs and Benefits of a Biomass-to-Ethanol Production Industry in California, Draft Final Consultants Report P500-01-002, by Arthur D. Little, March 2001, at http://www.energy.ca.gov/mtbe/ethanol/index.html

[191] The graph was obtained from the California Energy Commission website (http://www.energy.ca.gov/gasoline/graphs/ethanol_18-month.html). It's unclear how "Fuel Ethanol" is defined; it's assumed that this is synonymous with "Fuel Grade Ethanol," which is essentially neat ethanol.

[192] No survey response was received from the ethanol interest on the TAG for the 2001 Market Assessment, or for the 2003 update.

[193] National Ethanol Vehicle Coalition, "What is the Price of E-85?", website (www.e85fuel.com/faqs/priceofe85.htm), as of May 21, 2003.

[194] A gallon of E85 (85% ethanol and 15% gasoline, by volume) contains about 71% of the energy found in a gasoline gallon.

[195] The supply noted to be attainable for 2003 was up to 660 million gallons of ethanol. Up to 990 million gallons have been cited as the potential demand for 2004 (see Footnote 188).

[196] William J. Keese, Chairman, California Energy Commission, "Causes for Gasoline and Diesel Price Increases in California," March 28, 2003, from website (http://www.energy.ca.gov/2003_price_spikes/2003-04-02_GASOLINE_FINAL.PDF),

[197] Peg Guttman, Ford Motor Company, TAG input to the Energy Commission, March 20, 2003.

[198] California Air Resources Board, "E85 Fuel – CARB Research and Development Application Guidelines Dated May 27, 2003," online (http://www.arb.ca.gov/vapor/e85rdappguide_052703.pdf), downloaded July 2003.

[199] California Air Resources Board, "E85 Fuel – CARB Research and Development Application Guidelines Dated May 27, 2003," online (http://www.arb.ca.gov/vapor/e85rdappguide_052703.pdf), downloaded July 2003.

[200] As noted by one TAG member, other states have implemented E85 stations despite this constraint.

[201] Source - http://www.afdc.doe.gov/altfuel/eth_general.html

[202] The automaker most aggressive in making such announcements has been Daimler Chrysler, which had previously indicated that it will commercially introduce methanol-fueled FCVs based on the NECAR 5 concept by 2002. However, Daimler Chrysler's latest plans for methanol FCVs have not been publicly announced.

[203] Methanol would have to compete with other "hydrogen carrier" fuels, possibly including gasoline, with its fully developed fueling infrastructure.

[204] Most underground tanks in the greater Los Angeles area are already methanol-compatible, due to SCAQMD Rule 1170, which requires that "at least one tank be compatible when one or more underground motor vehicle fuel storage tanks are installed or replaced."

[205] Challenges include how to achieve adequate flame luminosity (visibility) and address vapor flammability concerns.

[206] Survey response from Methanex Corporation, October 2000.

[207] Methanol contains about 57,000 btu/gal, while gasoline contains about 115,000 btu/gal (both LHVs).

[208] National Renewable Energy Laboratory, Alternative Fuels Data Center, website (http://www.afdc.nrel.gov/altfuel/met_general.html).

[209] Much of this information was obtained from "Methanol Refueling Station Costs," prepared for the American Methanol Foundation, by EA Engineering, Science, and Technology, Inc., February 1999.

[210] This is the case for most underground tanks in the greater Los Angeles area. Since 1988, SCAQMD Rule 1170 has required that "at least one tank be methanol-compatible when one or more underground motor vehicle fuel storage tanks are installed or replaced."

[211] XCELLSiS, began as a collaboration between Daimler-Chrysler, Ballard Power Systems and Ford to build and deploy fuel cell engines with electric drive systems. In late 2001 Ballard Power Systems acquired all interests in XCELLSIS.

[212] From XCELLSiS website (www.xcellsis.com) in mid 2001. XCELLSIS is now part of Ballard Power Systems.

[213] These M85 stations cannot be confirmed from cleancarmaps.com or other web-based station mapping programs.

[214] It is noteworthy that the various types of E85 FFVs currently available in California use similar technology as formerly available M85 FFVs. Reintroduction of M85 FFVs to the California market would not involve major changes in vehicle hardware or software.

[215] California Fuel Cell Partnership, "Hydrogen Fuel Station Facility Description," from website http://www.fuelcellpartnership.org/factsheet) as of May 21, 2003.

[216] For example: J.M. Ogden, "Developing a Refueling Infrastructure for Hydrogen Vehicles: A Southern California Case Study," International Journal of Hydrogen Energy, 1999, and J.M. Ogden, M. Steinburler and T. Kreutz, "A Comparison of Hydrogen, Methanol and Gasoline as Fuels for Fuel Cell Vehicles," Journal of Power Sources, vol. 79, pp. 143-168, 1999.

[217] U.S. Department of Energy, Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development and Demonstration Plan, draft report.

[218] Source: based on Table 41 of Guidebook for Evaluating, Selecting, and Implementing Fuel Choices for Transit Bus Options, Transportation Cooperative Research Program Report 38, Transportation Research Board, National Academy Press, 1998

[219] Personal communications to Jon Leonard (Arthur D. Little) from Susan Brown and Ken Koyama (California Energy Commission), 02/01/01.

[220] This was the case with OCTA's Garden Grove LNG facility (see LNG station section).

[221] California Fuel Cell Partnership, "Hydrogen Fuel Station Facility Description," from website http://www.fuelcellpartnership.org/factsheet) as of May 21, 2003

[222] National Renewable Energy Laboratory, Blueprint for Hydrogen Fuel Infrastructure Development, NREL Publication NREL/MP-540-27770, January 2000, online at http://www.eere.energy.gov/hydrogenandfuelcells/pdfs/mp27770.pdf.

[223] Blueprint for Hydrogen Fuel Infrastructure Development.

[224] Matthew R. Simmons, Simmons & Company International, "Energy Jitters Again," presentation to the Greater Houston Partnership Board Meeting, March 5, 2003.

[225] While sharing of stations may make sense from an economic standpoint, logistics to actually make such arrangements can be difficult (e.g., union issues, liability concerns, billing accuracy concerns, etc.).

[226] Over the longer term, LDVs using clean fuels (e.g., methanol or direct hydrogen) are expected to deliver zero or near-zero emissions while simultaneously displacing large volumes of gasoline fuel.

[227] In previous model years (2002 and 2001), one engine family (Acura 3.5 L MDX) achieved the SULEV standard with gasoline.

[228] California Energy Commission, Task 2: Base Case Forecast for California Transportation Energy Demand, Staff Final Report P600-01-019F, March 2002.

[229] California Air Resources Board, California's Plan to Reduce Diesel Particulate Emissions: Fact Sheet, October 2000.

[230] California Air Resources Board, "CARB Identifies Diesel Particulate Emissions as a Toxic Air Contaminant," Press Release 98-51, August 27, 1998.

[231] California Air Resources Board, Staff Report: Initial Statement of Reasons – Proposed Regulation for a Public Transit Bus Fleet Rule and Emission Standards for New Urban Buses, January 27, 2000.

[232] Although transit agencies are not required to purchase alternative fuel buses certified to an optional low-NOx credit standard (2.5 g/bhp-hr NOx or lower), those are the only certified alternative fuel bus engines currently available. In addition, bus engines certified to an optional low-NOx credit standard can qualify for incentive funding.

[233] Fax from Alvaro Gutierrez, California Air Resources Board, to Jon Leonard on April 10, 2001.

[234] These numbers are educated estimates, according to SCAQMD. The actual number and rates of AFVs introduced will be affected by 1) each fleet rule's phase-in rate and exemptions, 2) availability of various AFV types, 3) fleet turnover rates, 4) available funding. On average, full phase-in of these rules is expected to occur between 2010 and 2015.

[235] California Air Resources Board, California's Plan to Reduce Diesel Particulate Emissions: Fact Sheet, October 2000.

[236] U.S. Environmental Protection Agency, Heavy-Duty Engine and Vehicle Standards and Highway Diesel Fuel Sulfur Control Requirements, December 2000.

[237] Under an R&D program jointly funded by the Energy Commission, the SCAQMD and NREL, efforts are being made to develop and certify 0.5 g/bhp-hr NOx HD engines. However, according to ARB staff (public hearing on transit fleet rule, October 24, 2002), no heavy-duty alternative fuel (or diesel) engines meeting that standard are projected to be certified by the 2004 model year.